THE USE OF QUASIORTHOGONAL SWEEPS FOR SIMULTANEOUS SOURCING IN VIBROSEIS SURVEY

Vladimir Ignatev, Geodevice LLC, Russian Federation
Alexander Oshkin, Moscow State University, Russian Federation
Aleksei Tarasov, Saint Petersburg State University, Russian Federation
Andrey Shuvalov, Saint Petersburg State University, Russian Federation
Andrey Konkov, Saint Petersburg State University, Russian Federation

Abstract

Simultaneous acquisition techniques allow obtaining greater volumes of data and sophisticate its recording geometry through the use of several sources. Depending on the method of seismic (vibrational or pulse), different methods of signals separation are used. In this study, we demonstrate some methods of constructing uncorrelated signals for vibroseis simultaneous acquisition, their application on the example of synthetic data and the removal of the cross-correlation noise on the synthetic seismogram with use of hyperbolic median filtering.

Introduction

One of the main factors determining where and how seismic surveys will be carried out is their cost. As the corresponding technologies develop, the demand for larger and more complex seismic operations rises. Therefore, now more than ever, there is a need to increase the efficiency of these operations.

Currently, one can observe an increasing interest in simultaneous acquisition techniques for improvement of the effectiveness of seismic operations. The principle of this method is to use several sources located at an arbitrary distance from the observation system and recorded simultaneously within the write cycle. Vibroseismic method, in contrast to the pulse method, allows separating data from several sources at the stage of correlative processing of vibrograms. To achieve this, it becomes necessary that signals from several sources have a low level of cross-correlation. For this purpose, so-called pseudorandom signals and pseudorandom sequences are used in many ways (Weik, 2001). Furthermore, pseudorandom signals are characterized by improved noise immunity and by form of autocorrelation function that is better than for classical chirp sweep (Sallas ea al., 2008).

After the data on correlograms are separated, the cross-correlation noises remain, the level of which increases with increasing of the number of sources used. These noises are inevitable when working with several sources and lie in the frequency band of the useful signal. In this regard, algorithms to deal with random noise that are based on the signal spectrum may not be effective. The use of nonlinear filtering methods, such as median filtering (Huo et al., 2009), can solve this problem.

Methods

Phase-shift keying signal

Phase-shifted signals (PSK) are widely used in information transmission systems with multi-user access (for example, CDMA - Code Division Multiple Access) (Ipatov, 2005). Changing the phase of the signal by 180˚ is equivalent to changing the sign of the carrier within one rectangular pulse S (t). The duration of a rectangular pulse is T = 1 / f_0, where f_0 is the carrier frequency. Using the control sequence $\vec{a}$, whose elements take the values +1 or -1, the signal can be written as:

$$W(t) = \sum_{k=0}^{N-1} a_k S(t - kT) \sin 2\pi f_0 t \quad (1)$$

Figure 1a shows the phase-shifted signal segment (the signal envelope is highlighted in red) and its amplitude spectrum in Figure 1b. The signal frequency f_0 = 75 Hz, the number of elements in the sequence N = 1023, the duration of the signal is N * T≈13.6 s.

For simultaneous use of several sources, it is necessary that the signals have a low level of cross-correlation. The mutual correlation of two PSK signals (W (t) and V (t)) constructed using different sequences ($\vec{a}$ и $\vec{b}$ respectively) is:

$$R_{wv}(t) = \sum_{m=-\infty}^{\infty} R_{ab}(m) R_s(t - mT) \quad (2)$$

$$R_{ab}(m) = \sum_{l=0}^{N-1} a_l b_{l-m} \quad (3)$$

Here R_s is the autocorrelation of one carrier period, and R_{ab} is the cross-correlation of two sequences. To calculate the autocorrelation of the signal it is necessary to substitute the same sequence. Figure 2a shows an example of the autocorrelation function of the PSK signal. An example of cross-correlation of two PSK signals with different control sequences is depicted in Figure 2b.

Thus, in order to construct noncorrelating signals with good properties of autocorrelation functions, it becomes necessary to use sequences that have the same properties for manipulation. Many sequences have been developed, such as m-sequences (Wong, 2013), Barker codes (Barker, 1953), Gold codes (Gold, 1967), Kasami codes (Welch, 1974), etc., which have useful correlation properties when it comes to periodic correlation functions calculation. However, for the goals in seismic survey, it is necessary to calculate aperiodic correlation functions in connection with what the sequence data may not be optimal. Moreover, these sequences are not determined for an arbitrary length of the sequence, and their truncation leads to unfavorable results. Therefore, the problem of constructing uncorrelating sequences with minimal noise of autocorrelation arises.

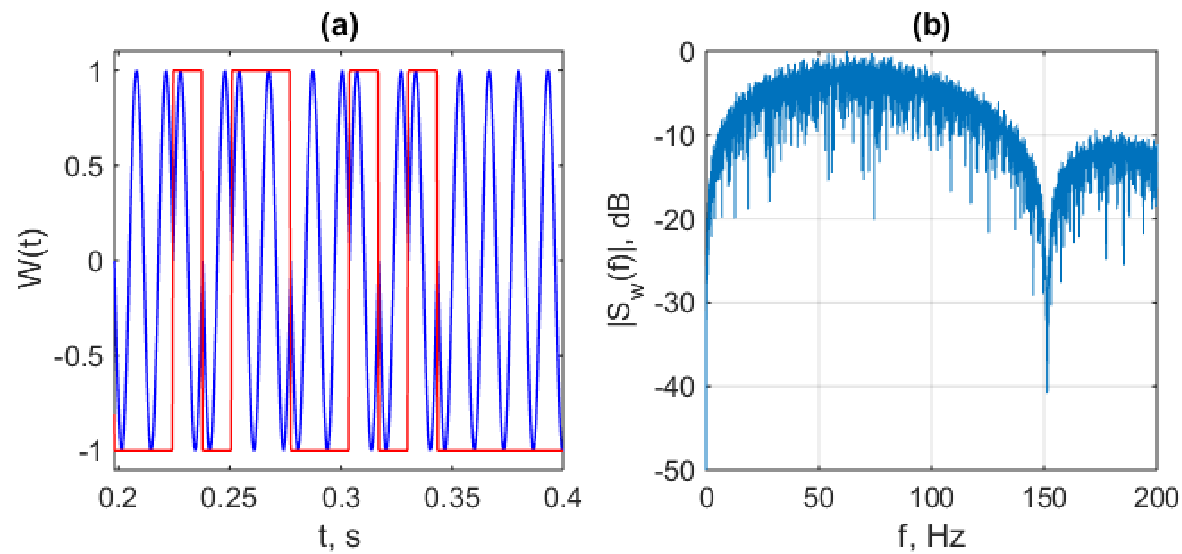

Figure 1: a) A segment of PSK signal with 13.6 s duration and a carrier frequency of 75 Hz, b) Amplitude spectrum of PSK signal.

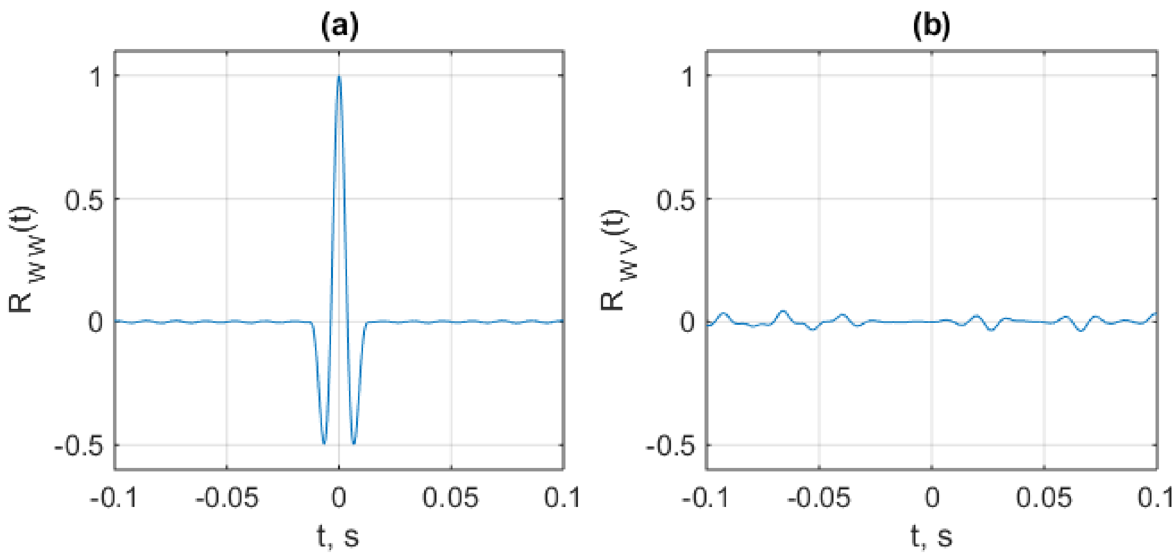

Figure 2: a) The autocorrelation function of the signal from Fig. 1a, b) The correlation function of two PSK signals controlled by different sequences.

Binary sequences design

A sequence whose elements can take two values is called binary. Signals built on the basis of a binary sequence are of great interest, since their energies are equal. This is especially important in seismic operations, since in this case the sources are equivalent and seismograms are obtained with the same dynamic range. To construct optimal sequences, the optimization problem was posed. As the control parameters of the functional, the integrated sidelobe level (Soltanalian, 2012) of two sequences and integrated cross-correlation level were used. They are defined as:

$$ISL(\vec{a}) = \sum_{k=1}^{N-1} |R_a(k)|^2 , \quad ISL(\vec{b}) = \sum_{k=1}^{N-1} |R_b(k)|^2 \quad (4)$$

$$ICCL(\vec{a},\vec{b}) = \sum_{k=1}^{N-1} |R_{ab}(k)|^2 \quad (5)$$

Since it is impossible to minimize simultaneously the noise of autocorrelation and cross-correlation functions, the following functional was used to construct optimal binary sequences:

$$F_\theta(\vec{a},\vec{b}) = \theta[ISL(\vec{a}) + ISL(\vec{b})] + (1-\theta)ICCL(\vec{a},\vec{b}) \quad (6)$$

This functional was minimized through the genetic algorithm with additional restrictions on the values of the elements in sequence. Individuals $\vec{x}$ were built as a class of sequences $\vec{x} = [\vec{a}^T \ \vec{b}^T]^T$. The optimal value of the control parameter $= 0.55$.

Hyperbolic median filter

A hyperbolic median filtering (HypMF) method is proposed for filtering the noise of cross-correlation. This method utilizes the kinematic properties of the target reflected waves.

The HypMF algorithm consists in constructing a certain set of vectors formed from the samples of the seismogram from a given range of traces, selecting one vector with the minimum variance from the whole set, and then calculating the median element of this vector. Further, the median value is "placed" in the sample, for which this set was built. A set of vectors is formed along different parts of hyperbolas (enclosed in a given window), which pass through the filtered sample at different velocities values. This method can effectively eliminate incoherent noise and maintain useful reflected waves.

Figure 3 illustrates an example of picking the correct theoretical hodograph.

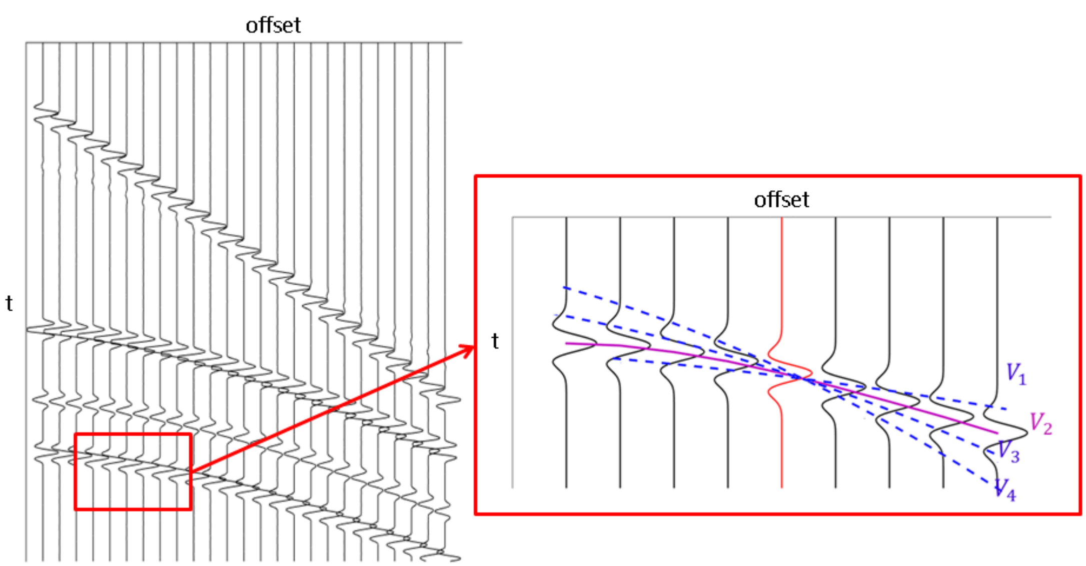

Figure 3: Selection of the vector with the smallest variance. Such a vector passes through the line-up.

Conclusions

During the tests, two signals with a carrier frequency of 75 Hz and a duration of 13.6 s were constructed, which were then convoluted with a synthetic pulse seismogram. On the resulting vibrorecord the noise was superimposed, after what a correlogram for the first source was calculated (Figure 1a). The correlogram of the first source contains residual autocorrelation noise, cross-correlation and superimposed noise. The use of hyperbolic median filtering enabled to effectively eliminate the noise and identify target waves (Figure 2b).

In this paper, the effectiveness of application of quasi-orthogonal signals and hyperbolic median filtering for simultaneous acquisition techniques was demonstrated. The sequences constructed by the proposed method can also be effectively used in other methods of constructing signals on their basis (Omijeh and Oteheri, 2016, Tang and Clement, 2009). Hyperbolic median filtering can also be utilized as a powerful tool for pulse sources separation during marine seismic operations.

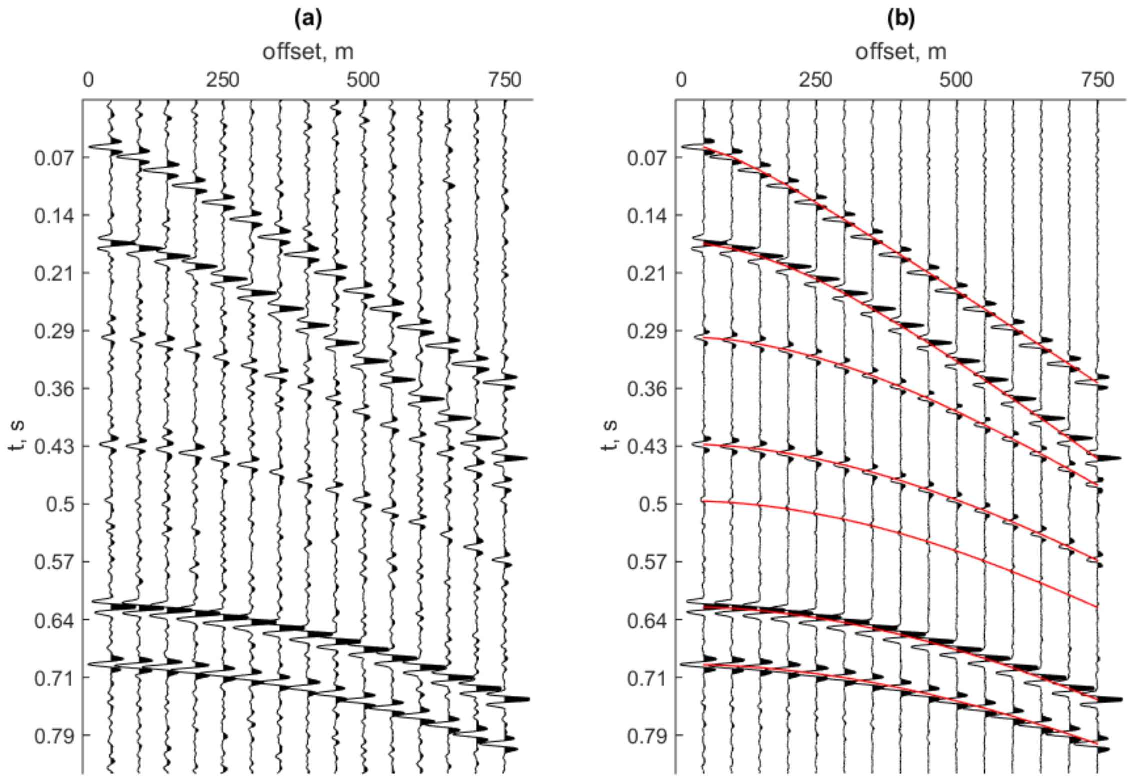

Figure 4: a) Correlogram of the first source after separation, b) The result of HypMF application. The red lines correspond to the hodograph curves of the pulse seismogram.

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Acknowledgements

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