Non-Parametric Detection of Seismic Signals by Two Parts of the Same Amplitude Spectrum

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Abstract. A signal detection non-parametric method in passive seismic location system has been investigated. The seismic signal from a target is detected by the comparison of the corresponding spectral components of the amplitude spectrum reference part and working part. The paper contains the detection characteristics obtained by statistical simulation.

Keywords: *passive seismic location, seismic signal, detection, non-parametric method, Fast Fourier Transformation*.

1 Introduction

The great attention is focused on the detection of a target like a person with pulse action of the ground surface. Detection in any kind of location demands supporting the given values of false alarm probability when correct detection probability is maximized [3].

The person detection algorithm based on acoustic and seismic signals spectrums is proposed in [4], where human occurrence in a PSL observation zone a-posteriori probability is found with help of the Bayesian approach. This approach provides the correct detection probability about 70% while the false alarm probability is not considered.

The person seismic signal detection algorithm based on symbol dynamical filtration (SDF) where the wavelet transformation is made in the time domain. The target detection probability is calculated with respect to finite probability machine state change. To improve detection reliability it is proposed to use geophones together with infrared sensors [5]. However it makes the PSL system more expensive and complicated.

The seismic signal detection algorithm based on autocorrelation functions in the time domain is proposed in [6]. Unfortunately this approach disadvantage is that algorithm calculation time directly depends on correlation interval.

The seismic signal detection procedure with the wavelet coefficients correlation analysis is proposed in [7]. The useful signal coefficients are separated from the noise coefficients. Certain detection characteristics are not analyzed. The wavelet transformation advantage is capability of non-stationary signals properties study. However wavelet transformation practical application is complicated by enormous calculation time.

Neural networks are applied in seismic signals detection and classification in [8, 9]. The perceptron neural network [8] operating with seismic signal spectral components is able to provide false alarm probability about 1% which is too much for practically used PSL systems. The back propagation neural network with zero-cross counter and energy ratios separately integrated over high frequencies and low frequency are described in [9].

Neural networks have noticeable shortcomings including complicated architecture for a certain task and training results difficult interpretation [10]. Neural network parameters values cannot be explained in terms of a solved problem. Hence a neural network remains a “black box” both for a researcher and a user. Root-mean-square error minimization by optimization methods leads to network overtraining [11]. Network sensitivity to noise strongly depends on its architecture. Providing correct detection probability more than 90% requires enormous hierarchical architecture where first the criterion vector is processed by a rough network, then obtained solution is corrected by more accurate and slower network. Neural networks training demand big volumes of experimental data acquired at certain environment conditions. Neural network qualitative training detecting a seismic signal is difficult in regions where abrupt air temperature and moisture change can often take place.

The mentioned above papers are not focused enough on the seismic signal detection with respect to the Neiman-Pearson criterion.

The non-parametric detection based on a zero-cross counter was considered in [12]. This approach gives less calculation time than the mentioned above approaches. The number of zero crossings reduces when seismic signal target component appears in an observed signal. The signal is detected after the noise decorrelation or “whitening”. The also whitened useful signal remains correlated. Hence zero crossing number statistically decreases in comparison with the only seismic noise. Such detection is not very good because of high requirements of whitening quality. However, instant adaptation for noise properties changes is almost impossible.

The paper proposes the procedure of non-parametric detection of seismic signal in the frequency domain..

2 Statement of Purpose

The investigation purpose is to develop and research the seismic signal non-parametric detection procedure in the frequency domain where the amplitude spectrum reference part and working part are analyzed with respect to the Neiman-Pearson criterion. While allowable false alarm probability is fixed the correct detection probability should be maximized. It is also interesting to study how amplitude spectrums averaging influences on detection probability.

3 Theory

A PSL system usually consists of a group of sensors placed under the ground surface as it is shown in [1]. Distance between adjacent sensors is commonly about 10 m. When a seismic target acting on the ground surface appears, the signals generated by it are accepted by one or several sensors. These sensors compose a group of active sensors. Their signals are preliminary processed for the following detection procedure. The examples of sensed signals of some targets like people, animals or vehicles are stated in [1] as several 1000 sample cycles.

Initial signals are sampled with 600 Hz sampling frequency. Then separate sensors signals are divided into 1000 samples cycles for further processing. Such cycle corresponds to the time interval 1.67 s. The signals are whitened to suppress the seismic noise.

Signal samples in each cycle are transformed into the amplitude spectrum by the Fast Fourier Transformation (FFT). The *n*-th cycle signal $Sx_n,\ n=\overline{1,N}$ is the vector of J elements. The signal cycles $Sx_n, n=\overline{1,N}$ are transformed by FFT into the corresponding spectral vectors $X^{(n)}=\left\|x_j^{(n)},\ \ j=\overline{1,J}\right\|,\quad n=\overline{1,N}$. Each cycle amplitude spectrum is divided into the reference part with the corresponsing harmonics numbers $Y^{(n)}=\left\|x_j^{(n)},\ \ j=\overline{j_1,j_2}\right\|,\quad n=\overline{1,N}$ and the working part, displaced down relative to the reference part by Δj harmonics $Z^{(n)}=\left\|x_j^{(n)},\ \ j=\overline{j_1-\Delta j,j_2-\Delta j}\right\|,\quad n=\overline{1,N}$. The decision statistics $U(Y,Z)$ is generated with respect to the cycles averaging:

$$U(Y,Z)=(1/N)\sum_{n=1}^{N}U^{(n)}(Y^{(n)},Z^{(n)})\,. \tag{1}$$

Then the decision on presence or absence of a seismic target (ST) is made according to the rule:

$$U(X,Y)\geq U_0\ \Rightarrow \text{"}ST\ is\ present;\ U(X,Y)<U_0 \Rightarrow\ \text{"}ST\ is\ absent\text{"} \tag{2}$$

The statistics $U(Y,Z)$ is generated by the local statistics of separate cycles $U^{(n)}(Y^{(n)},Z^{(n)})$, which are, in turn, are formed with respect to the rule:

$$U^{(n)}(Y^{(n)},Z^{(n)})=\sum_{j=j_1}^{j_2}u(x_{j-\Delta j}^{(n)}-x_j^{(n)})\,, \tag{3}$$

where $u(\zeta)=\begin{cases}1 & \text{at } \zeta\geq 0\\ 0 & \text{at } \zeta<0\end{cases}$. The values $\zeta_j^{(n)}=u(x_{j+\Delta j}^{(n)}-x_j^{(n)}),\quad j=\overline{1,J/2},\quad n=\overline{1,N}$ are the elements of an independent binary sequence of zeros and ones with the uniform probability distribution $p_0=p_1=0{,}5$, if the samples Y and Z are generated by seismic noise and homogeneous. The elements are independent because stationary random process spectral samples are known to be uncorrelated [13] and described by the Gaussian distribution. It was proposed in [14] to use reference and working parts of spectrums in different cycles. . However it is necessary to implement the complicated correction procedure to provide the harmonics independence.

Fig. 1 contains an example of the seismic signal amplitude spectrum for a target like a person. There is a typical boost at the harmonics from 50 to 150. This spectrum is like a spectrum of seismic noise at other frequencies. Therefore, the range from 50 to 150 is taken as the spectrum working part while the displaced range, for example, from 250 to 350 harmonic (with the upwards offset 200), is accepted as the reference part

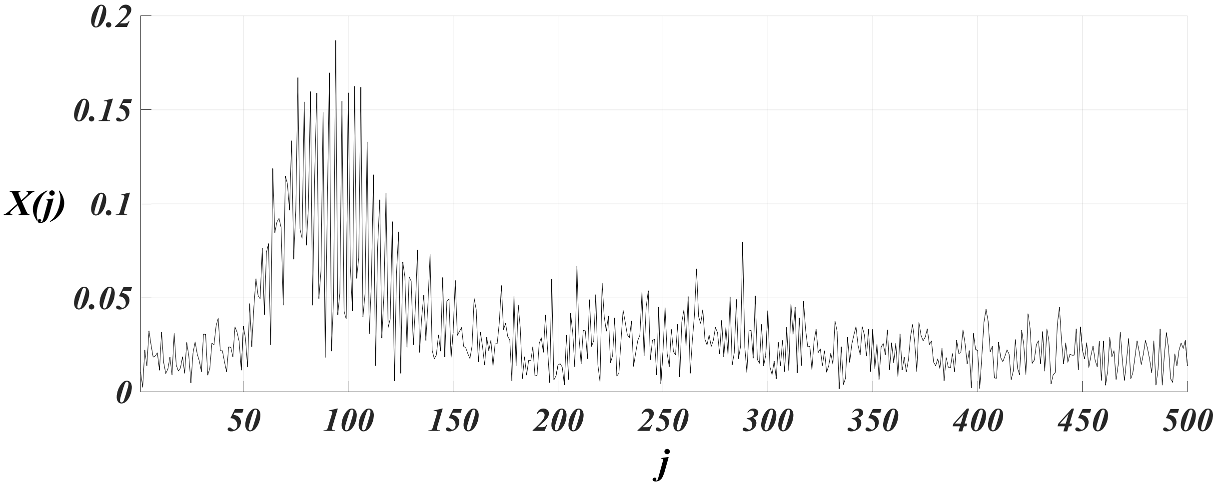

Figure 1. Person seismic signal amplitude spectrum

3 Simulation

The series of M=2000 cycles of seismic noise and person signal were generated by means of computerized simulation. The number of cycles K where the decision "ST is present" was made according to the rule (2) was counted. Then the ST detection probability was calculated as

$$P_D = K / M \ . \tag{4}$$

The results of simulation were used for building the detection characteristics including the false alarm probability dependence on detection threshold and the correct detection probability on signal-to-noise ratio (SNR) at several false alarm probability values.

If N=2 then correct detection probability at the same false alarm probabilities significantly increases while the necessary calculation time also becomes longer

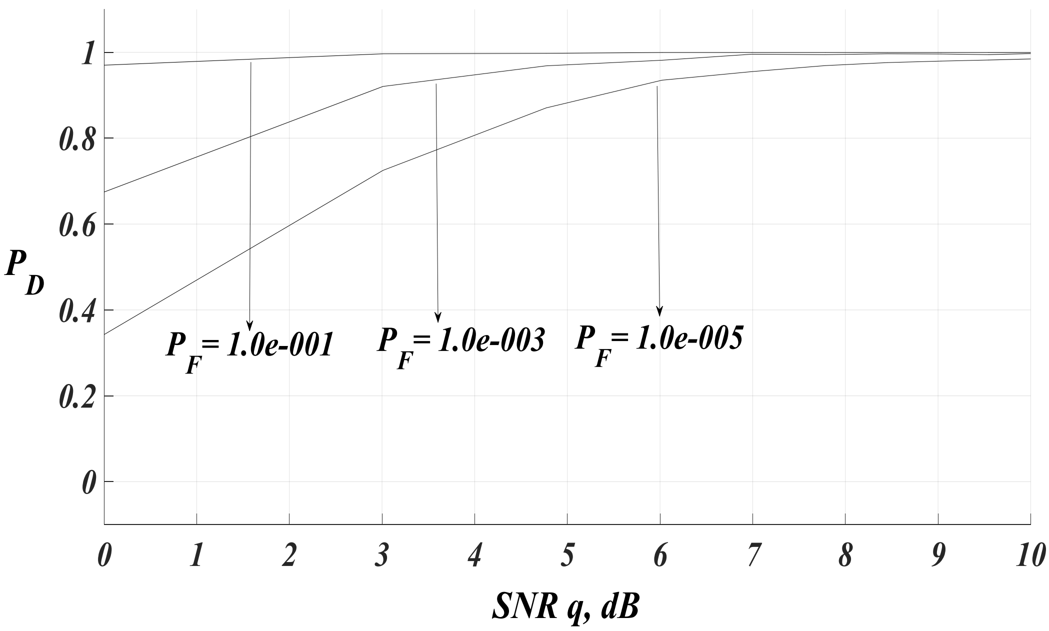

Figure 2. Correct detection probability dependence on SNR at N=1

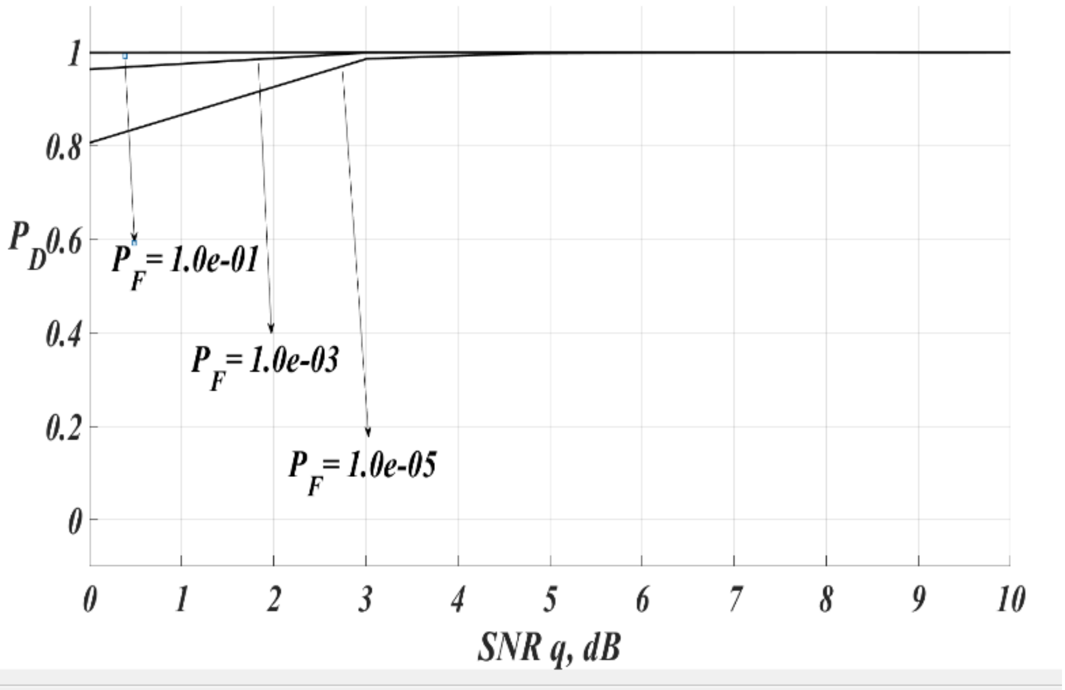

Figure 3. Correct detection probability dependence on SNR at N=2

3 Conclusion

The proposed seismic signal non-parametric detection method, based on counting amplitude spectrum harmonics in the working part exceeding corresponding harmonics in the reference part, provides high enough detection probability at fixed false alarm probability level achieved by the proposed algorithm non-parametric property. If, for example, false alarm probability is 0.001 and SNR is 5 dB, then correct detection probability is more than 0.9. If the mentioned above spectral components exceeding number is averaged over two cycles, correct detection probability becomes extremely higher at similar false alarm probabilities and SNR. The proposed non-parametric detection method is useful when there is a-priori uncertainty when there is no enough information on signals statistical properties. Further it would be interesting to test the proposed method for other targets with impulse action on the ground surface.

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