Shahrood University of Technology

JOURNAL OF RESEARCH ON APPLIED GEOPHYSICS

(JRAG)

2019, VOL 5, NO 1

(DOI): 10.22044/JRAG.2017.898

Iranian Geophysical Society- 1975

Time-varying residual phase estimation and correction in seismic data

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Received: 18 December 2016; Accepted: 25 March 2017

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Keywords

Non-Stationary Phase Estimation
Statistical Analysis
Kurtosis
Constant-Phase Rotation
Tikhonov Regularization

Extended Abstract

Summary

The residual phase estimation and correction of a post-stack seismic section is important and necessary. The remaining non-stationary phase detection of data without the use of well logs information can be made using statistical methods. Kurtosis maximization approach by constant-phase rotation is the most popular post-stack statistical methods that can reveal the non-stationary phase of seismic data. Kurtosis criterion is a fourth-order statistics that preserves the wavelet phase information and plays an important role in seismic data interpretation. In this paper, we change the problem of regularized kurtosis maximization for non-stationary phase estimation that is presented by van der Baan and Fomel (2009) to reduce significantly the computational volume while maintaining the quality of our results. The proposed approach due to lower computational volume, and also, the fewer number of free parameters is more efficient than similar regularization approaches. Therefore, for large-scale data analysis, it is easier to use. The effectiveness of the proposed technique for identifying and correcting the non-stationary residual phase of the seismic signals are shown on both synthetic and field data.

Introduction

Phase as the most important characteristic of seismic signals is one of the key indicators in the seismic interpretation stages. Over the years, many researchers with different ideas and techniques have been working on the problem of statistical phase estimation. At first, the stationary phase of the data was estimated by applying the constant-phase rotation approximation and measuring the amount of signal deviations from Gaussianity (or kurtosis criterion). The kurtosis criterion was then extended to the framework of local regularized criterion to identify the non-stationary form of the phase. Here, we estimate the non-stationary seismic phases to be more accurate than previous approaches by changing the behavior of kurtosis as a new regularization criterion.

Methodology and Approaches

The non-stationary phase estimation by kurtosis maximization can be considered as an inverse problem and can be solved using the Tikhonov regularization. The general formula of kurtosis considers the kurtosis as a global quantity and estimates the phase of the wavelet with uncertainty. For improving the accuracy of the phase estimation technique, we need to introduce the kurtosis in the form of a local quantity. This means that we should increase the number of possible choices of maximum kurtosis value to achieve the optimum phase of the data.

We factorize the kurtosis, $k[x]$, as the product of two local variables b and d :

$$k[x]=\left(\frac{1}{E[x^2]}\right)\left(\frac{E[x^4]}{E[x^2]}\right)-3=bd-3$$

where $E[.]$ indicates the expectation operator and the constants b and d are the global solutions of the least-squares minimization problem.

Local estimation of the time-varying quantities b and d is then possible by adding regularization constraint R and solving independently the following two optimization problems:

$$b=\arg\min_b \sum_i \left(\frac{1}{x_i}-x_i b_i\right)^2+\lambda_b^2[Rb]_i^2 \quad , \quad d=\arg\min_d \sum_i \left(x_i^3-x_i d_i\right)^2+\lambda_d^2[Rd]_i^2$$

where, λ is the regularization parameter.

Finally, the local kurtosis maximization $k[x_i]$ is given by $k[x_i] = b_i d_i - 3$.

Results and Conclusions

We proposed a novel approach that can reveal the optimum non-stationary phase of a wavelet by casting the problem into the framework of local kurtosis maximization. By applying the proposed algorithm on synthetic and real data examples, more stable behavior of the new approach was observed in comparison with similar methods. The developed technique can be used as an interpretational tool to detect the correct location and exact acoustic impedance of seismic layers in the high-resolution seismic sections.