Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2018-0065

Vol. **28**, No. 1, pp. 477-497
July 2020

Estimating Primaries by Sparse Inversion with Cost-Effective Computation

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Received 15 March 2018; Accepted (in revised version) 13 October 2018

Abstract. Recently, attenuation of surface-related multiples is implemented by a large-scale sparsity-promoting inversion where the primaries are iteratively estimated without a subtraction process, which is called estimation of primaries by sparse inversion (EPSI). By inverting for surface-free impulse responses, EPSI simultaneously updates the primaries and multiples, both of which contribute to explaining the input data, and therefore promote the global convergence gradually. However, one of the major concerns of EPSI may lie in its high computational cost. In this paper, based on the same gradient-descent framework with EPSI, we develop a computationally cost-effective primary estimation approach in which a newly defined parameterization of primary-multiple model is adopted and an efficiently defined analytical step-length is developed. The developed approach can yield a better primary estimation at less computational cost as compared to EPSI, which is verified by two synthetic datasets in numerical examples. Moreover, we apply this approach to a shallow-water field dataset and achieve a desirable performance.

AMS subject classifications: 65K10, 86-08, 86-A22

Key words: Inverse problem, multiple removal, primary estimation, impulse response.

1 Introduction

Nowadays, multiple removal is still a fundamental step in the conventional seismic data processing [30, 31, 34, 35], even though seismic imaging using multiples is widely investigated in recent years [32, 33, 36, 37]. Multiple removal is implemented as a prediction-subtraction process for many techniques, such as surface-related multiple elimination

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(SRME) [4, 26], which has achieved a widespread adoption in industry due to its practicality. Despite its major success over the years, SRME still have limitations in many cases, such as: 1) subtraction based on minim energy constraint can hardly yield a satisfactory result when primaries and multiples interfere with each other [12, 15]; 2) as the strongest contributor of multiples, the near-offsets of the input data are absent due to the acquisition gap especially for shallow water data, which makes it a necessity for near-offset data reconstruction [2,7,27]. Therefore, geophysicists increasingly shift their attentions towards the demultiple methods that the primary estimation is implemented with an explicit full-wave inversion [10, 11, 14, 19, 20, 25, 28, 29]. Among these methods, the approach of estimation of primaries by sparse inversion (EPSI) attracts great attention. This approach integrates nears-offset data reconstruction into multiple removal without a subtraction process [19].

By parameterizing primaries with wavelets and spike-like impulse responses, EPSI directly estimates the primaries through inversion, which potentially conserves the primaries even in case that primaries and multiples seriously interfere with each other [10]. Additionally, with its new insight into geophysical signal separation, EPSI has been successfully applied in various aspects, such as passive seismic data, blended data and ocean-bottom cable data [1, 9, 18, 21–24]. Despite its great success in many cases [17], the EPSI algorithm still has some limitations.

As the impulse response is parameterized as a series of spikes, lots of free parameters need to be defined to determine the sparsity of the gradient in each iteration. This shortcoming limits the flexibility and practicality of the EPSI algorithm, and may ultimately affect the reliability of the final result [10]. Therefore, some geophysicists made refinements for the EPSI algorithm to eliminate the number of free parameters [10,11,14].

Another challenge faced by EPSI may lies in its high computational cost. To ensure the convergence and minimize the artifacts, a large number of iterations are required in general. Specifically, in each iteration, the spike-like impulse response is used to update the primaries and multiples, both of which explain the input data until the energy of residual is controlled in an acceptable scope. Usually, tens of iterations, with each one involving a multi-dimensional correlation and convolution, are needed for a satisfactory final primary estimation. Therefore, reducing the computational cost or accelerating the convergence is an important issue for EPSI [6, 8, 13]. In addition, the spike-like impulse response is determined through imposing the sparsity to the gradient by the practitioner (due to the sparsity and causality). When the multiples in the input data are explained with a low rate, the multiple impulse response would be wrongly selected as the primary impulse response, which cannot be eliminated in the subsequent iterations and therefore causes an irretrievable result. Thus, accelerating the convergence not only results in a lower computational cost, but potentially contributes to a more reliable primary estimation.

Based on the same gradient-descent framework with the EPSI algorithm, we develop a computationally efficient algorithm in which a newly defined parameterization of primary-multiple model is adopted for accelerating the convergence, and an analyti-