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Interface Controlled Multiple Elimination by Sparsity Inversion

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Abstract. Removing internal multiples remains an important but challenging problem in seismic processing. The generalized Estimation of Primaries by Sparsity Inversion (EPSI) method minimizes data residuals between the calculated and observed waveform using the sparse constraint of primary impulse responses to predict multiples and remove them directly, instead of using the conventional adaptive subtraction method. Even though the generalized EPSI method provides a good estimate of the primaries and multiples when they overlap, it is limited by intensive computational cost.

In this paper, we introduce two strategies to improve computational efficiency. First, the interface-controlled strategy is introduced by only selecting high-amplitude primary responses related to the interfaces with strong impedance contrasts to estimate multiples. The computational time is approximately proportional to the number of involved reflectors and usually, most of the internal multiple energy in the data is only related to a few strong reflectors. Therefore the modified method can remove most of the internal multiples in fewer computations than in the generalized EPSI, which loops through all the interfaces. Next, an approximate formula for estimating primary impulse responses is proposed by neglecting a computationally intensive term which corresponds to the primary responses estimated from internal multiples. According to our analyses and experiments, in most cases, the contribution of this term is negligible because the internal multiples are weak. Therefore, the computational efficiency can be improved without significantly losing quality when estimating most primaries and multiples.

In order to demonstrate this, multiple elimination of a two-layered simple data and the Pluto data are implemented. We find that the modified method can yield reliable results that require fewer computations. The improvements of the modified method may encourage the use of the generalized EPSI method in industry.

AMS subject classifications: 86-08, 86A15, 86A22

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Key words: Multiple, internal multiple, interface-controlled multiple elimination, estimation of primaries by sparsity inversion.

1 Introduction

Primary reflections are dominating in seismic datasets and considered as the most effective data for most popular subsurface imaging techniques in the surface reflection seismic exploration. Therefore, multiples especially in marine data are regarded as noises reducing imaging quality in most processing algorithms. The multiples (including internal and surface-related multiples) significantly contaminate subsurface images and thus reduce the reliability of reservoir prediction and well location design. In shallow water data, the reverberation caused by multiple reflections between free surface and the seabed is such a serious problem that it is very tough to distinguish the primaries without suppressing multiples. In recent years, multiple subsurface imaging techniques and some primary and multiple joint imaging techniques, that exploit multiples instead of removing them, have been developed to improve the illumination in subsalt area [1–5]. However, in most applications, especially in oil and gas industry, the primaries and multiples are still required to be separated before the seismic imaging. Therefore, accurate estimation of primaries and multiples is still an important aspect of both primary imaging techniques and the multiple imaging techniques.

Multiples are defined as waves that have undergone more than one upward reflection before they are measured (ghost waves are not included). The upward reflection indicates the upgoing waves that reflect at the interface and turn to propagate upward. According to the position that the upgoing reflection takes place during the propagation, multiples can be divided into two types: the surface-related multiples and the internal multiples. Surface-related multiples are multiples that reflect at the surface at least once, and the internal multiples are those that reverberate in the subsurface interfaces without surface reflections. For instance, in marine exploration seismology, surface-related multiples are multiples that reflect at the sea surface, and internal multiples are those that reflect at the sea bottom, sediment interfaces and other impedance interfaces, such as salt dome boundaries.

Over the past few decades, two types of methods for suppressing multiples have been developed and optimized: the filtering method and the wave-theory-based method. Filtering techniques are based on signal analysis, which includes domain transform filter and predictive deconvolution [6–8]. These methods have been widely used and have been very successful in industry. However, it is difficult to estimate non-periodic multiples produced by the complex underground structures. Wave equation-based methods make full use of the kinematic and dynamic characteristics of wave propagation to estimate the primaries and multiples. Wave equation-based methods can be further divided into two categories: the two-step prediction-subtraction method and the sparse constraint inversion method. In the prediction-subtraction multiple elimination approach,