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A Bipolar-Bisection Piecewise Encoding Scheme for Multi-Source Reverse Time Migration

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Abstract. Conventional shot-record reverse time migration (RTM) suffers from a high computational burden when dealing with massive data. The computational cost of RTM can be reduced by shot-encoding techniques, and plane-wave encoding is a commonly used and effective shot-encoding scheme. However, plane-wave encoding requires long time padding to avoid information loss, which decreases the efficiency of the time-domain wavefield extrapolator, and the time padding becomes longer with the increasing distance between multiple sources. The piecewise plane-wave encoding scheme cuts multiple sources into several segments prior to implementing plane-wave encoding, hence reduces the time padding, but brings new crosstalk due to the mutual interference between shots in different source segments. We suppress the crosstalk artifacts by a new bipolar-bisection amplitude encoding method, in which half of the encoding array of each migration is different from that of any other migrations to reduce the number of crosstalk terms with as few migrations as possible. We embed the bipolar-bisection method into piecewise plane-wave encoding. Compared with plane-wave encoding, the proposed scheme requires considerably shorter time padding and thus works more efficiently and can generate a qualified imaging result. The feasibility of the proposed method is tested on the 2D SEG/EAGE salt model and the Marmousi model.

AMS subject classifications: 86-08, 86A15, 86A20

Key words: Reverse time migration, crosstalk artifacts, shot encoding, computational efficiency.

1 Introduction

Target subsurface areas in seismic exploration have recently become increasingly complex. Imaging these complex zones requires both high-quality data and accurate imaging

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methods. Complex geological structures, such as salt domes, can disturb or decrease the seismic energy and result in a lack of seismic illumination. One approach to obtaining sufficiently effective data is to collect large amounts of redundant information from wide-azimuth and full-azimuth techniques of seismic data acquisition [10, 19]. The large amounts of data require a significant amount of time for processing and imaging. On the other hand, the reverse-time migration (RTM) imaging method [1, 12, 26], which is based on the two-way wave equation, is a powerful seismic imaging algorithm and can handle steep dips and large lateral velocity variations. However, conventional shot-record RTM (i.e., processing one shot per migration) suffers from a high computational burden and requires an enormous amount of memory when dealing with massive data.

Encoding techniques are widely used to improve the efficiency of inversion and migration [8, 16, 22, 27]. We can linearly combine the data of many shots that have been weighted with an encoding function prior to migration because of the linearity of the wave extrapolator. Imaging with encoded composite shots implies potentially fewer migrations to process the data of all shots. However, this multi-source imaging strategy has a disadvantage: the cross-correlation imaging condition leads to crosstalk artifacts [15]. Crosstalk is usually strong enough to seriously damage the quality of the imaging result. Two types of encoding schemes are used to improve the quality of multi-source imaging results: phase encoding and amplitude encoding. Phase encoding can shift or disperse crosstalk artifacts [16], and many phase encoding schemes have been developed such as plane-wave encoding [17, 23, 24], random phase encoding [13, 16], modulated encoding [18], and harmonic-source encoding [29]. Amplitude encoding blends different shot-encoding migrations together, and the crosstalk amplitude can be attenuated during this process [8]. Other typical methods include the encoding scheme with truncated singular value decomposition [7], Hartley encoding [8], and encoding based on the orthogonal cosine basis [9].

Godwin and Sava [8] (2013) compared shot-encoding schemes for wave-equation based migration and found that plane-wave encoding is an optimal shot-encoding scheme in many ways. Recently, plane-wave based methods have been widely used for migration [5, 11, 15, 17, 20, 21, 24, 28]. Plane-wave decomposition converts surface-recorded seismic data from (x,t) to (τ,p), where τ is the intercept time, p is the ray parameter, and each ray parameter corresponds to a particular angle of incidence for the data [21]. Methods of calculating the range and sampling interval of the ray parameters of the plane waves have been proposed [6, 17, 28]. Plane-wave encoding methods require sufficient migrations depending on the range and sampling interval of the ray parameter, and inadequate plane waves, i.e., migrations, may result in poor crosstalk cancellation [14, 17]. Plane-wave encoding is a linear time-delay encoding method based on the distance of the shotpoints from some reference locations. Therefore, plane-wave encoding requires long time padding to avoid information loss, which seriously decreases the efficiency of the time-domain wavefield extrapolator.

In this paper, we present a bipolar-bisection piecewise encoding scheme. We execute a source partition for multiple sources prior to implementing plane-wave encoding. This