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A Modified Multiple Matching Method Based on Equipoise Pseudomulti-Channel Filter and Huber Norm

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Abstract. This study is aimed at improving multiple adaptive subtraction. We propose a modified pseudomulti-channel matching method based on the Huber norm, to adjust the matching differences on frequency and phase between the predicted multiples and original data. The second-order derivative of the predicted multiples is utilized to replace the derivative of its Hilbert transform. Due to the additional frequency term, this method can enhance the high-frequency component. We introduce 180° phase rotation of the multiple channels, which can decrease phase differences. The Huber norm interpolates between smooth L2 norm treatment of small residuals and robust L1 norm treatment of large residuals. This method can eliminate the restriction of large value conditions from the L2 norm and weaken the condition of orthogonality from the L1 norm. The applications of the Pluto and Delft models shows that compared with pseudomulti-channel matching filter, the main frequency is increased from 36 Hz to 38 Hz, and the primary reflection wave is more concentrated. The practical application of field data verifies the effectiveness of the proposed method.

AMS subject classifications: 74J25, 86A15, 86A22, 86A60

Key words: Multiple, adaptive matching filter, equipoise pseudomulti-channel, Huber norm, second-order derivative.

1 Introduction

In conventional seismic data processing, multiple waves are often regarded as interference, especially for marine seismic data, which have many multiple waves. Elimination of multiple waves is generally a critical step. There are two categories of elimination methods, one based on the difference between multiples and effective signals, and the

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other on wave equations. The latter utilizes a data-driven mode and needs little or no a prior information, such as the depth and velocity of the subsea. This type of method can achieve a good suppression effect and is currently a primary object of research. All of the current data-driven approaches, whether they use the feedback iterative method [1,2] or wavefield extrapolation method [3], have the two parts of prediction and subtraction. The predicted multiples are not likely to accurately coincide with the original data, including amplitude, arrival time, phase, and frequency. Therefore, a matching filter is required to achieve elimination when subtracting the predicted multiples from the original data.

There are many methods of adaptive matching filtering. The Wiener filter [4] can be implemented in both the time and frequency domains. The efficiency of the frequency Wiener filter suffers lower efficiency due to the associated nonlinear optimization problem. The time Wiener filter, by contrast, is simple and widely used. The pattern matching filter [5] requires predictability of events and is not ideal when the medium has strong lateral variations under complex conditions. The independent variable analysis method [6] is a kind of blind signal-separation technique that is only suitable when there is no time-shift between the multiple trace and original trace. The complex curvelet transform method [7] can correct the time-shift error well, but the processes of amplitude and phase correction are complicated.

We choose the time domain Wiener filter for its computational cost and effectiveness. The corresponding minimum-energy criteria can use different norms. For the L2 norm, it is fast to realize but sensitive to noise interference. Tarantola [8] proposed this norm's statistical interpretation on the interference signal. The L2 norm rests on two assumptions: multiples and primary reflection waves should have minimum energy differences, and they should be orthogonal. If not, there will be multiple solutions and the matching effect is neither satisfactory nor acceptable. Error measurement based on the L1 norm is common in geophysics. This norm has lower sensitivity to noise and is more robust than the L2 norm [9]. In addition, it has no restriction on large-value conditions, hence the energy difference between multiples and primary reflection waves should not be too large [10]. By adding a threshold parameter on the L1 norm and adopting a non-causal filter along the time axis, Xiong et al. [11] improved the matching effect and reduced the computation time. Unfortunately, with zero residual, the gradient of the L1 norm is singular and small errors are often amplified, so this criterion is often not applicable.

Considering the smoothness to small residuals of the L2 norm and the stability to large residuals of the L1 norm, the Huber norm is proposed [12]. This criterion is continuous at zero residual, uses the L1 norm for large residuals, and weights small residuals with the L2 norm. Ekblom and Madsen [13] deduced this optimization method. Guitton and William [14] used the Huber norm for velocity analysis and proved that it had higher stability than the least square method with damping. The complex Huber norm is applied to waveform inversion, and the gradient discretization formula of the Huber norm is deduced by Taeyoung et al. [15]. Its robustness to outliers and coherent noise is verified by Marmousi data. More recently, Li [16] calculated seismic curvature attributes