Journal of Applied Geophysics 117 (2015) 67–72

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

An efficient and effective common reflection surface stacking approach using local similarity and plane-wave flattening

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ARTICLE INFO

Article history:
Received 24 December 2014
Received in revised form 24 February 2015
Accepted 25 February 2015
Available online 27 March 2015

Keywords:
Common reflection surface (CRS) stacking
Similarity-weighted stacking
Plane-wave flattening
Zero-offset image

ABSTRACT

We propose an efficient and effective approximate common reflection surface (CRS) stacking approach to obtain a clean zero-offset (ZO) seismic image. Since the basic purpose of CRS stacking is to first stack along offset direction and then smooth along midpoint direction, we propose to first use local similarity as the weight to stack pre-stack seismic data along offset dimension and then to use plane-wave flattened events as the integral surface along midpoint dimension for stacking. Compared with the classic CRS stacking approach, we only need to calculate the local slope and to scan the normal moveout (NMO) velocity in the proposed two-step approximate CRS approach, thus it is more efficient and applicable to real seismic data processing. Both synthetic and field data examples demonstrate a successful performance of the proposed approach.

1. Introduction

To obtain a clean, high-resolution, and structure-preserved seismic image is the key in seismic exploration. We can use post-processing strategy to obtain a cleaner seismic image by applying some denoising techniques (Chen and Ma, 2014; Chen et al., 2014b; Yang et al., 2015; Chen et al., 2015a). We can also investigate more sophisticated imaging algorithms to obtain a better seismic image during migration processes (Baysal et al., 1983; Farmer et al., 2006; Xue et al., 2014; Chen et al., 2015b). The conventional NMO/DMO stack (Chen et al., 2014a) and pre-stack migration methods (Wapenaar et al., 1987; Berkhout, 1997) to obtain simulated zero-offset (ZO) section need precise macro-velocity model and cannot provide the best illumination for the reflecting interface in the subsurface. The common reflection surface (CRS) stack, however, is an entirely data-oriented seismic reflection imaging approach of ZO section simulation in a macro-velocity model independent way, and this method needs only information of near-surface velocities. In this paper, we propose an efficient and effective approximate CRS stacking approach, based on two steps processing: stacking along the offset direction using local similarity based weights and then smoothing along the midpoint direction following local slope (Fomel, 2002) based on plane-wave flattening. One synthetic and two field pre-stack datasets demonstrate superior performance of the proposed approach over traditional approaches.

2. Method

2.1. Common midpoint gather stacking

The conventional common midpoint gather stacking can be expressed as:

$$S(t_0, m_0) = \int P(\theta(h; t_0), m_0, h) dh, \tag{1}$$

where $\theta(h;\, t_0)$ denotes the hyperbolic reflector:

$$\theta(h; t_0) = \sqrt{t_0^2 + \frac{4h^2}{v^2}}, \tag{2}$$

where t_0 and m_0 denote the ZO two-way traveltime and common midpoint (CMP) position, h is the half source–receiver offset, m_0 is the space location, and v is the time-migration velocity.

2.2. Common reflection surface stacking

The common reflection surface stacking can be expressed as:

$$\hat{S}(t_0, m_0) = \iint P\left(\hat{\theta}(m, h; m_0, t_0), m, h\right) dm\ dh, \tag{3}$$

where $\hat{\theta}(m, h; m_0, t_0)$ is the common reflection surface (Dell and

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http://dx.doi.org/10.1016/j.jappgeo.2015.02.029
0926-9851/

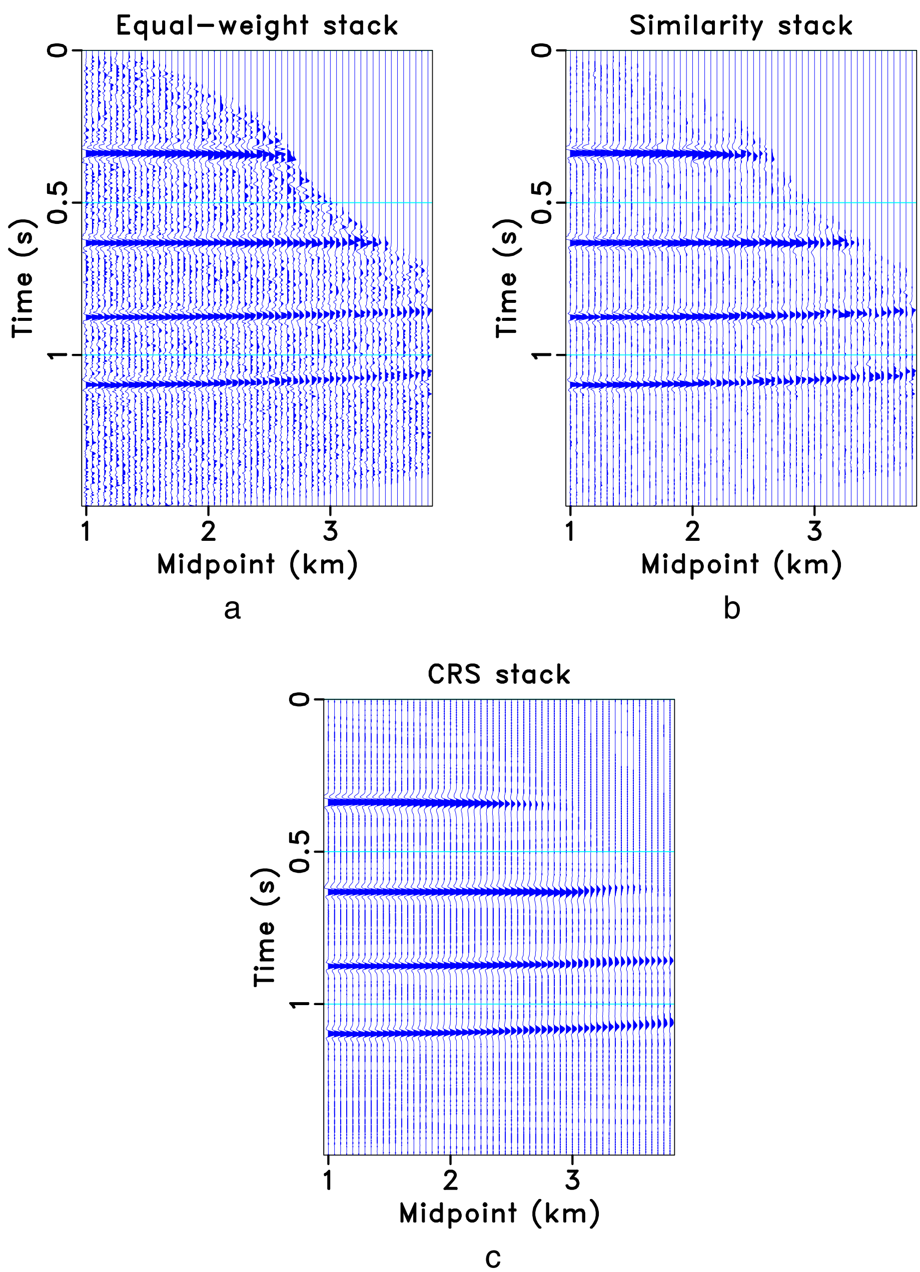

Fig. 1. Synthetic data example. (a) Conventional equal-weight stack. (b) Similarity-weighted stack. (c) Common reflection surface stack.

Gajewski, 2011):

$$\hat{\theta}(m,h;m_0,t_0) = \sqrt{(t_0 + 2p_m(m+m_0))^2 + 2t_0(M_N(m+m_0)^2 + M_{NIP}h^2)}, \quad (4)$$

where p_m, M_N and M_{NIP} are the stacking parameters that define the shape of the CRS trajectory, $p_m = \partial t/\partial m$ is the first-order horizontal spatial traveltime derivative with respect to the midpoint coordinate m, $M_N = \partial^2 t/\partial m^2$ is the second-order horizontal spatial traveltime derivative with respect to midpoint coordinate, and $M_{NIP} = \partial^2 t/\partial h^2$ is the second-order horizontal spatial traveltime derivative with respect to the half-offset coordinate.

In order to implement the classic CRS algorithm, we have to detect the three coefficients: p_m, M_N and M_{NIP} as functions of t_0 at selected locations m_0 and then stack pre-stack seismic data over the full range of offsets and a small range of midpoints around each m_0. The implementation of a classic CRS algorithm may not be efficient due to calculation of different parameters and also may not be effective because of incorrectness of the CRS relation (4) for complex subsurface structure.

In this paper, we propose a two-step approximate CRS stacking method, inspired by analyzing the basic purpose of the classic CRS method. Because the CRS algorithm accomplishes two tasks simultaneously: stacking to ZO section and smoothing across midpoint dimension to attenuate random noise and increase signal-to-noise ratio. Thus, we propose our approximate CRS stacking method by stacking each common midpoint gathers using a similarity-weighted stacking technique (Liu et al., 2009), and then stacking a small range of midpoint locations along the local structure of seismic events. The local structure