Fast Gabor imaging with spatial resampling

Yongwang Ma and Gary F. Margrave

ABSTRACT

Gabor depth imaging method has been made much more efficient thanks to adaptive partitioning algorithms. Moreover, as introduced in another space-frequency domain imaging method, called the forward operator and conjugate inverse, wavefield extrapolation operator lengths at low frequencies can be decreased, resulting in a lower computation cost. This is known as the spatial resampling technique, which can be implemented in the Gabor imaging method because this imaging method works in the space-frequency domain, too. In this paper, we demonstrate the application of spatial resampling in the Gabor imaging method, which will substantially improve the imaging speed.

INTRODUCTION

Gabor imaging theories have been described by Grossman et al. (2002) and Ma and Margrave (2006). In the Gabor imaging method, wavefields are localized with spatial windows, and then Fourier transformed across windows and extrapolated to new depths. A simple way to implement Gabor imaging is to use evenly distributed small windows across the lateral coordinate. These small windows (called *atomic* windows) are usually set to address the most rapidly varying velocities in the lateral direction at a depth step. As a result of this setting, there is redundancy in these atomic windows. Adaptive partitioning algorithms (Grossman et al., 2002; Ma and Margrave, 2007) have been introduced to eliminate redundant windows. Gabor imaging deals with the wavefield that is temporal frequency (hereinafter frequency) dependent.

In a simple case of extrapolation, we have a thin slab without any lateral velocity variation, a homogeneous layer. The adaptive partitioning algorithm automatically uses one wide window across the lateral coordinate. Therefore, we need one forward and one reverse spatial Fourier transforms for the source field and the recorded data field, respectively; at each depth step, four spatial Fourier transforms are needed to transform seismic data back and forth between the spatial and wavenumber domains. These processes have to be done frequency by frequency. In a general case, we usually expect lateral velocity variations and more windows at a depth step, meaning computation cost is several times higher.

The number of depth steps in a typical depth marching migration can be several hundred. The number of frequencies usually is from several hundred to more than a thousand. The production of the number of Fourier transforms related to a single window and those of depths, frequencies and windows at depths gives a very large number of Fourier transforms during the extrapolation process. Any reduction in those numbers will make Gabor imaging more efficient. Usually numbers of depths, frequencies in seismic depth migrations are set. However, we can eliminate redundant windows and alter lengths of extrapolation operators at low frequencies. We have implemented the former, and we describe the application of spatial resampling (Margrave et al., 2006) to shorten extrapolation operator lengths in Gabor depth imaging, which will be demonstrated in the following sections using the Marmousi synthetic data sets (Bourgeois et al., 1991).

SPATIAL RESAMPLING

Margrave et al. (2006) introduced spatial resampling in the forward operator and conjugate inverse (FOCI), a space-frequency domain imaging method. Many wavefield extrapolation methods use operators of fixed lengths, which would run into problems at low frequencies. That is, the fixed-length operator incurs poor phase and instability in extrapolations due to the evanescent components in the operator when working with low frequencies.

To address this problem, the spatial resampling technique was suggested by Margrave et al. (2006). In their paper, they mentioned the advantage of using this techniques. That is, resampling can improve the extrapolation speed due to shorter operator lengths after spatial resampling at low frequencies. We use spatial resampling to make a more efficient Gabor depth imaging method.

The first step of the implementation is to break frequencies into small bands as (Margrave et al., 2006)

$$[\omega_{min}, \omega_{max}] = [\omega_{min}, \omega_1) \cup [\omega_1, \omega_2) \cup \ldots \cup [\omega_{n-2}, \omega_{n-1}) \cup [\omega_{n-1}, \omega_{max}] \tag{1}$$

where ω_{min} and ω_{max} are the minimum and maximum frequencies, respectively, from band-limited seismic data. Suppose we have the original (fixed) spatial sampling interval as Δx; we resample it to new ones, Δx_j, according to various frequency bands, which are defined as

$$\alpha\left(\frac{\pi}{\Delta x_j}\right) \leqslant \frac{\omega}{v_{crit}} \leqslant \beta\left(\frac{\pi}{\Delta x_j}\right), \quad \alpha < \beta \in [0,1],\ \omega \in (\omega_{j-1}, \omega_j) \tag{2}$$

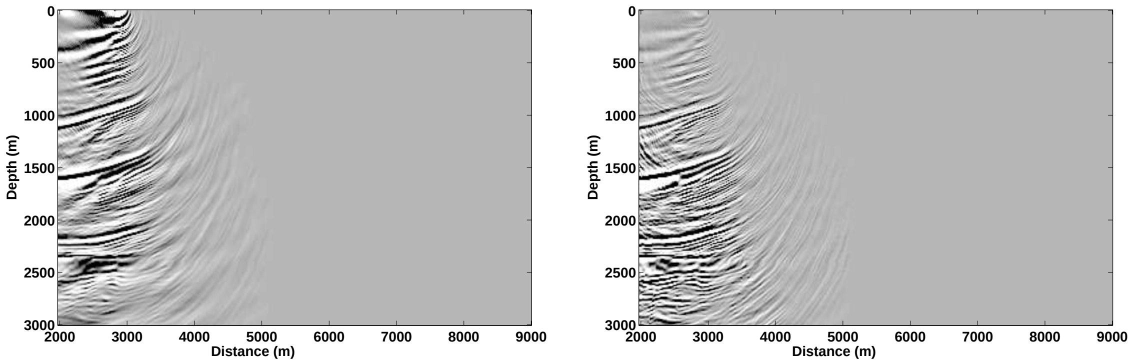
where v_{crit} is the velocity chosen to define the highest evanescent boundary.

Using spatial resampling, we always have $\Delta x_j > \Delta x$, which means that the extrapolation operators at low frequencies always have fewer discrete sampling points than the fixed number of points related to Δx. Shorter operators give faster Fourier transforms. Hence, we have a faster Gabor imaging than the one with fixed lengths of operators for all frequencies.

GABOR IMAGING EXAMPLES WITH SPATIAL RESAMPLING

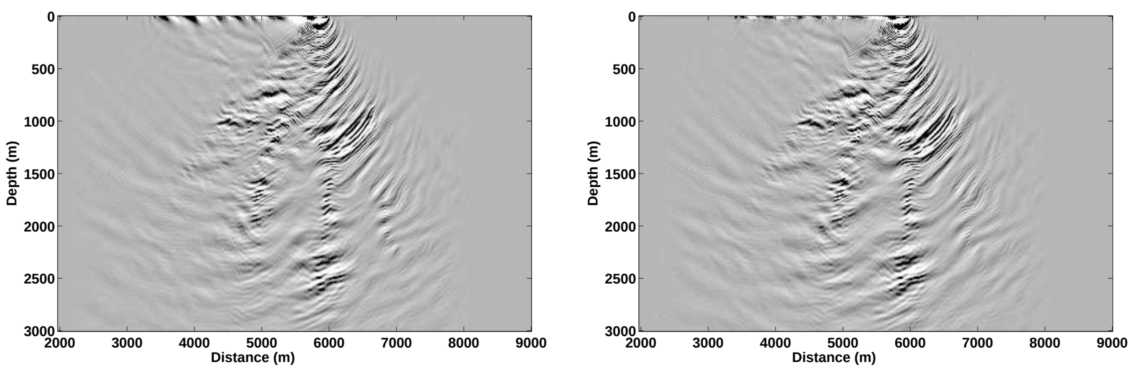
In this section, we show some imaging examples with the application of spatial resampling in the Gabor imaging method. Figure 1 (a) shows depth imaging of the first shot record in the Marmousi data sets using the fixed-length Gabor imaging method. Figure 1 (b) shows the image of the same shot record but using the Gabor imaging method with the spatial resampling. All the other imaging parameters such as accuracy criteria are all the same.

From visual comparison, we can see that these two images are similar to each other.



(a) (b)

FIG. 1. Migrations of the first shot record (a) without and (b) with the spatial resampling.



(a) (b)

FIG. 2. Migrations of the 120th shot record (a) without and (b) with the spatial resampling.

However, the shot migration using spatial resampling shows smaller amplitudes in the shallow part, and there are more obvious artifacts around depth 1500 m on the left edge of the image. If we look at the run time for each, we know that image in Figure 1 (a) consumed about 366 s, while the one in Figure 1 (b) used about 127 s. Figures 2 (a) and (b) show another two shot migrations for shot 120. We see images are very similar to each other. The image in Figure 2 (a) used 395 s CPU time, and Figure 2 (b) used 137 s.

For migration of all 240 shot gathers, we show the imaging results in Figures 3 (a) and (b). We can not visually tell the difference between the two. For the run time, Gabor imaging without the spatial resampling used 19 hours. The one with the spatial resampling used 7 hours. This shows that the Gabor imaging speed has been made roughly 3 times faster. These migrations were performed on a PC with a single CPU of 3.0 GHz. The lateral position error criterion used is 5 m.

One thing has been discovered recently is that the run times mentioned above may not be accurate, which means that when those migrations were running on the PC, they were not alone. A new tests on a laptop with a 1.6 GHz CPU show that shot 120 migration used 118 s. This indicates run time for Gabor imaging of all 240 shots using the spatial resampling should be less than 7 hours on the 3.0 GHz PC.

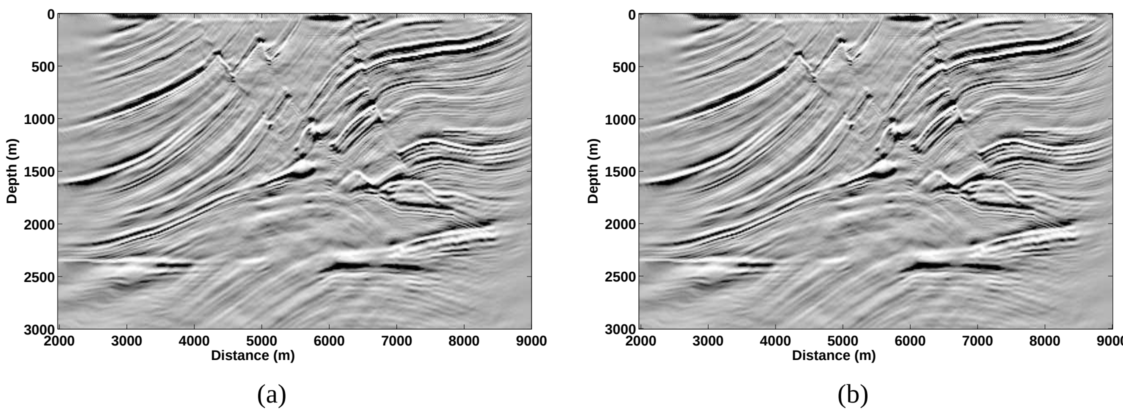


FIG. 3. Migrations of all 240 shot records (a) without and (b) with the spatial resampling.

CONCLUSIONS

The application of spatial resampling in Gabor depth imaging has made imaging speed about 3 times faster for the Marmousi synthetic data sets.

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