Denoise investigation on prestack reverse time migration based on GPU/CPU collaborative parallel accelerating computation

SHI Ying & TIAN Dong-sheng &KE Xuan
School of Earth Science, Northeast Petroleum University
Daqing, Heilongjiang, China
e-mail:shiyingdqpi@163.com

***Abstract*—Based on two-way wave equation, prestack reverse time migration (RTM) overcomes dip limitation, and can image complicated geological body with high precision. However, since the massy storage, large amount of computation, low frequency noise, the industrialization process of this approach develops slowly. High order finite difference algorithm is used to calculate reverse time migration in the paper. By GPU/CPU collaborative parallel accelerating computation, the computation efficiency of RTM has been greatly improved. The random boundary condition is adopted to obtain wavefield information. The paper discusses the theory and specific steps of Laplacian denoise approach. The tests on Marmousi and Sigsbee model illustrate that, by Laplacian operator denoise approach, prestack reverse time migration can image complicated geological body effectively and precisely. This approach has a wide application prospect.**

Keywords—migration; denoise; GPU; parallel;

INTRODUCTION

As the exploration block has become more and more complicated nowadays, prestack time migration can not meet the imaging demand in seismic exploration. While in prestack depth migration, prestack reverse time migration (RTM) based on two-way wave equation as a high-precision imaging approach, can image the turning waves, prism waves, and multiples, etc. This approach overcomes the limitation of migration aperture and dip, so it can image the complicated geological body exactly. The approach was proposed by Whitmore in 1983. Then many geophysicists did related investigations. Although its advantage is obvious, the problems of low frequency noise, massy storage, and large computation has restricted its development. To remove the low frequency noise, Chang and McMechan (1986) proposed ray-traced approach. Fletcher (2005) applied a directional damping term to non-reflecting wave equation to suppress the artifact during propagation. Yoon (2004) proposed using Poynting vectors to suppress noise. Zhang (2009) introduced Laplacian operator, and indicated that Laplacian filter is equivalent to tapering in angle domain, and needs not to output common imaging gathers in angle domain. In order to save storage, Robert G Clapp (2009) proposed random boundary condition. To decrease computation cost, Liu applied GPU to reverse time migration. Long (2009) investigated on 3D finite difference modeling on GPU cluster.

In the paper, we introduce GPU/CPU collaborative parallel computation into wavefield extrapolation and imaging to decrease computation cost, which improves computation efficiency, and shortens processing period of seismic migration imaging. We use random boundary condition to solve storage problem in RTM, which reduces the storage greatly but causes more computation. We suppress the unwanted low frequency noise by Laplacian operator filtering approach. Using methods mentioned above, prestack reverse time migration could be widely used in industry production.

BASIC THEORY OF RTM

Prestack reverse time migration technology is achieved by three steps. First, source wavefield propagate forward in time axis, then the wavefield information at every moment is stored on disk. Second, receiver wavefield propagate backward in time-reversed axis. Finally, image with the cross-correlation result of forward and backward propagate wavefield. Stack all shots migration result, then we can get prestack reverse time depth migration imaging data set.

Seismic wavefield propagation and imaging condition application play significant roles in reverse time migration algorithm. Wavefield information can be obtained by solving 2D acoustic wave equation with high-order finite difference. Acoustic wave equation is given by

$$\frac{1}{v(x,z)^2}\frac{\partial^2 P(x,z,t)}{\partial t^2} = \frac{\partial^2 P(x,z,t)}{\partial x^2} + \frac{\partial^2 P(x,z,t)}{\partial z^2} \tag{1}$$

Where x, z is space coordinate, t is time, $v(x,z)$ represents velocity of a certain point, $P(x,z,t)$ is the wavefiled at time t.

For equation (1), we use 2-order difference in time direction, 10-order difference in space direction, and cross-correlation imaging condition is used to image the wavefield at the same time. Cross-correlation imaging condition is given by

$$I(x,z) = \int_{-\infty}^{+\infty} S(x,z,t)R(x,z,t)dt \tag{2}$$

Where $I(x,z)$ represents imaging result at location (x,z), $S(x,z,t)$ and $R(x,z,t)$ represent forward wavefield and backward wavefield respectively. Discrete the equation above, we can get

$$I(x,z)=\sum_{t=0}^{t_{\max}} S(x,z,t)R(x,z,t) \tag{3}$$

Stack the imaging result of all single shots, then we can get imaging result of the whole data set.

GPU/CPU COLLABORATIVE PARALLEL ACCELERATING COMPUTATION TECHNOLOGY

GPU (Graphic Processing Unit) is well known for its parallel computation ability, which can be widely used in many fields. Compared with CPU, GPU has more transistors and execution units to process data. It also introduces share memory on chip, which improves computation efficiency greatly.

The core of RTM is made up of source wavefield forward propagation, receiver wavefield backward propagation and application of correlation imaging condition, which costs most of the computation time in CPU serial calculation. By GPU/CPU collaborative parallel accelerating computation based on CUDA architecture, wavefield propagation and correlation imaging can be accelerated in RTM algorithm.

When applying cross-correlation imaging condition, source wavefield and receiver wavefield are both needed, so one of them should be stored beforehand, which needs massy storage space. In this paper we apply random boundary condition to reduce storage demand. First, GPU accelerate source wavefield propagation forward, and only keep the wavefield at the maximum time, discard rest of the wavefield information. Then propagate source wavefield backward by random boundary condition from maximum time. At the same time, propagate receiver wavefield backward by cross-correlation imaging condition at every moment. Though this approach increases computation cost, it can solve storage problem in reverse time migration. Because of GPU acceleration technology, the increasing computation effects little on the efficiency of RTM algorithm. Main flow diagram of GPU acceleration is shown in Figure 1.

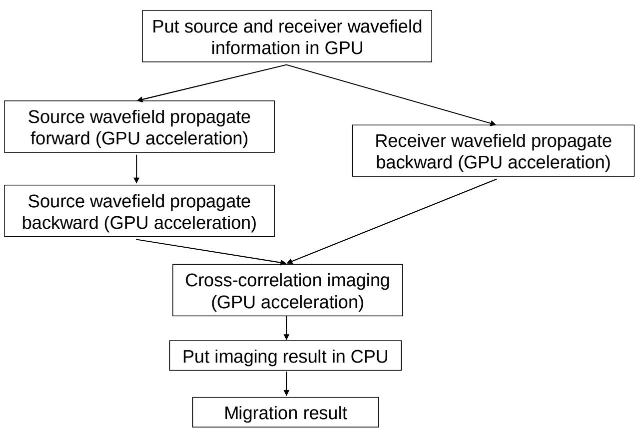


Figure 1. Flow chart for RTM algorithm by GPU acceleration

DENOISE BY LAPLACIAN OPERATOR

Noise in prestack reverse time migration is mainly caused by reflected waves from strong reflection interface, which could be attenuated by the following three approaches, wavefield propagation approaches, imaging condition approaches, post-imaging condition approaches. Usually, frequency from these artifacts is low, therefore in post-imaging condition approaches, we can suppress the artifacts by high-pass filter approach, least-square attenuation approach, Laplacian operator approach, etc. After reverse time migration imaging, Laplacian operator approach can be used to suppress noise, we can discrete it to 2-order, 4-order, or high order difference to improve its precision. 2D Laplacian operator is given as follows

$$\nabla^2=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial z^2} \tag{4}$$

In wave number domain, according to the law of cosines, Laplacian operator can be represented as follows

$$\nabla^2=-\frac{4\omega^2}{v^2}\cos^2\theta \tag{5}$$

Where θ is incidence angle, v is velocity. Equation (5) shows that applying Laplacian filter to the post-imaging result is equivalent to applying $\cos^2\theta$ weight to angle gathers. To use this approach without distorting the migrated spectrum and amplitude, we have to apply $1/w^2$ filter to the input data. Transform the data set to frequency domain, multiplied by compensation operator, then retransform them to time domain. After reverse time migration imaging, denoise by Laplacian operator, and compensate the velocity. Flow chart of denoise by Laplacian operator is shown in Figure 2.

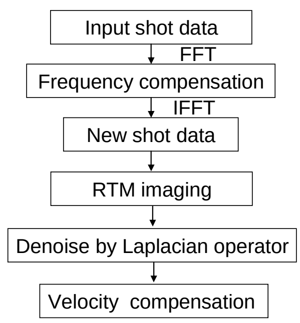


Figure 1. Flow chart for RTM dennoise by Laplacian operator

MODEL TEST

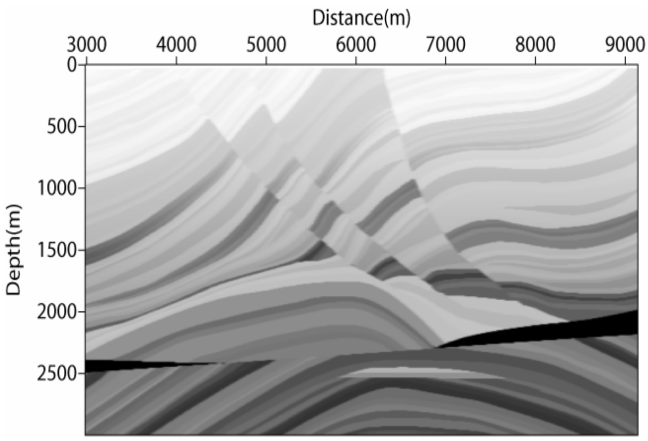
In this paper, two examples are given to test prestack reverse time migration algorithm.

One is Marmousi model. This model is used as a standard test data set for migration, inversion algorithm, and velocity analysis method. This model contains complicated geological features, including the shallow steep faults. In Marmousi model, source wavelet is ricker wavelet, the data size is 993×750, grid size is 12.5m×4.0m, total shots number is 240, 96 traces per shot, medium velocity is between 1500m to 5500m per second.

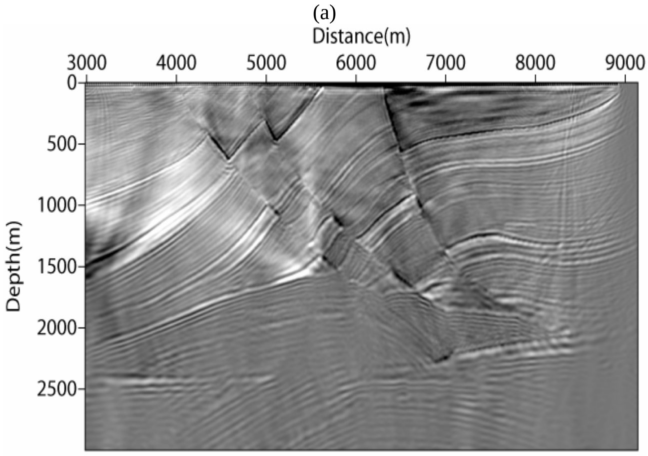
Computing platform on GPU is Nvidia Geforce GTX560, device memory 1024M, 256bits, core frequency 850 MHz, frequency of device memory 4500MHz. CPU is Intel i3, and local memory is 8G.

Computing time test show that CPU costs 53 minutes per shot, while GPU costs 37 seconds per shot. For the 240 shots data set, CPU costs 2720 min, while GPU costs 8800s. The efficiency improves about 86 times.

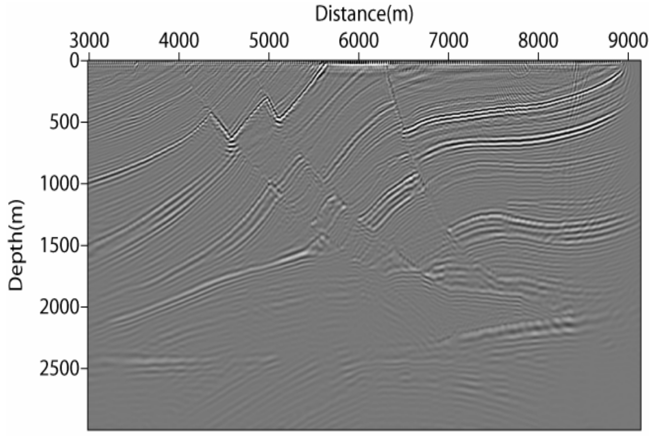
Marmousi velocity model is shown in Figure 3a. Reverse time migtation result by two-way acoustic wave equation and cross-correlation imaging is shown in Figure 3b, in which low frequency noise exists in certain degree, especially in shallow layer. Figure 3c shows denoise result by Laplacian operator, which demonstrates that Laplacian denoise approach could imaging structure underground exactly.



(a)



(b)

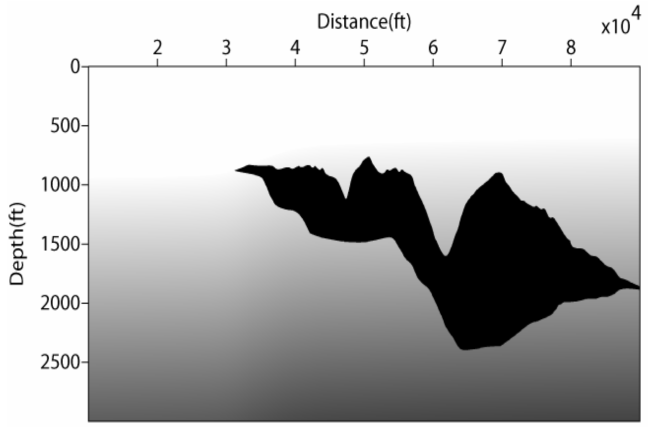


(c)

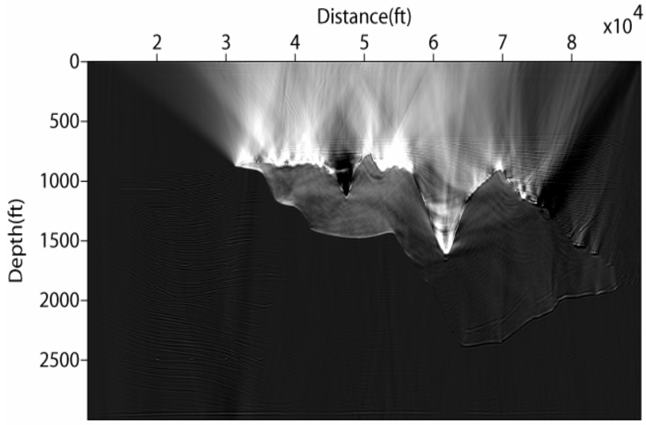
Figure 3. Marmousi model test
(a) Marmousi velocity model
(b) RTM result by cross-correlation imaging condition
(c) denoise by Laplacian operator

Another is Sigsbee model. The Sigsbee2A model features an absorbing free surface condition and a weaker than normal water bottom reflection, resulting in data do not contain free surface multiples and less than normal internal multiples. Additionally, there is a complex salt structure found within the model that results in illumination problems when processing and migrating the data. In Sigsbee model, source wavelet is also ricker wavelet, the data size is 30000 ft in depth and 80000 ft in length, grid size is 37.5 ft×25 ft, total shot is 500 shots, frequency is 40 Hz.

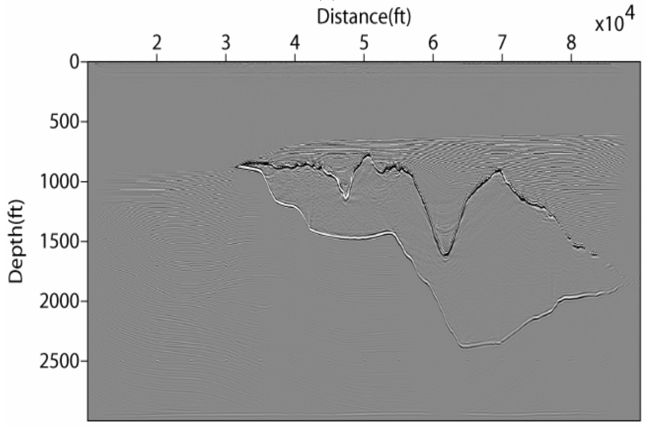
Sigsbee velocity model is shown in Figure 4a. Computing platform is the same as Marmousi model test. Reverse time migration result by cross-correlation imaging condition and GPU acceleration technology is shown in Figure 4b, where we can see low frequency noise in shallow layer. Figure 4c shows denoise result by Laplacian operator, where dip steep clearly imaged.



(a)



(b)



(c)

Figure 4. Sigsbee model test
(a) Sigsbee velocity model (b) RTM result by cross-correlation imaging condition (c) denoise by Laplacian operator

CONCLUSION

(1) The precision of prestack reverse time migration algorithm is high, and this approach can imaging complicated geological body. By introducing random boundary condition, reverse time migration reduces the memory storage but sacrifices the computation cost.

(2) By GPU/CPU collaborative parallel accelerating computation, the computation efficiency of reverse time migration increases greatly. For Marmousi model, computation efficiency improves about 86 times.

(3) Denoise by Laplacian operator can suppress low-frequency noise effectively, and improve imaging result largely.

(4) With the development and improvement of hardware and denoise approach, reverse time migration has a more wide application prospect.

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