

Quantitative regularity analysis of offset-vector sampling for seismic acquisition geometry

Wei Wei

*Institute of Geology and Geophysics
Chinese Academy of Sciences
No. 19, Beitucheng Xilu
Chaoyang District, Beijing, China
E-mail: caswei@gmail.com*

Li-Yun Fu

*Institute of Geology and Geophysics
Chinese Academy of Sciences
No. 19, Beitucheng Xilu
Chaoyang District, Beijing, China
E-mail: lfu@mail.igcas.ac.cn*

INTRODUCTION

SUMMARY

Symmetric acquisition geometry consisting of identical sampling of shots and receivers, can maintain the spatial continuity of the wavefield automatically, according to symmetric sampling theory. However, asymmetric geometry is often adopted in practical seismic exploration applications. Such geometry can cause uneven sampling and is necessary to be assessed for its sampling performance prior to acquisition. In conventional survey design, based on the common mid-point (CMP) analysis for a horizontally layered earth or common reflection point (CRP) analysis for a complex subsurface structure, the quality of acquisition geometry is generally judged by such bin properties as effective fold, offset scalar and azimuth distributions. However, these conventional approaches are limited by an incomplete understanding of the offset-vector sampling. Therefore, we propose a new method for quantitatively evaluating the continuity of offset-vector sampling including four spatial coordinates of shot and receiver. On the basis of physical potential energy and force-balance principle, it analyzes the regularity coefficient of offset-vector sampling as a whole using potential function model and takes into account fold, offset-scalar and azimuth distribution factors. The combination of regularity coefficients of every bin can produce spatial continuity distribution of offset-vector sampling. Similar to symmetric sampling, this approach emphasizes the spatial relationships between adjacent bins rather than single bin attribute, since it aims to maintain the spatial continuity of the wavefield which allows the faithful reconstruction of the underlying continuous wavefield. Using this method, we can quantitatively compare spatial continuity distribution for different seismic acquisition geometries, and then choose the better acquisition scheme.

Key words: Seismic acquisition geometry, quantitative regularity analysis, offset-vector sampling.

Current design techniques for 3D seismic acquisition geometries combine 3D symmetric sampling method (Vermeer, 2002), the rules of thumb (Cordson *et al.*, 2000), and limitations of available equipment (Stone, 1994). According to symmetric sampling theory (Vermeer, 1998), symmetric acquisition geometry consisting of identical sampling of shots and receivers, can maintain the spatial continuity of the wavefield automatically.

However, in some cases (e.g. when the budget is not adequate or in marine streamer acquisition), asymmetric geometry is often adopted in practical seismic exploration applications. Such geometry, which is far from 3D symmetric sampling criteria, can cause uneven sampling and is necessary to be assessed for its sampling performance prior to acquisition. In conventional survey design, based on the common mid-point (CMP) analysis for a horizontally layered earth or common reflection point (CRP) analysis for a complex subsurface structure (Slawson *et al.*, 1994), the quality of acquisition geometry is generally judged by such bin properties as effective fold, offset scalar and azimuth distributions. However, these conventional approaches are limited by an incomplete understanding of the offset-vector sampling.

Therefore, we propose a new method for quantitatively evaluating the continuity of offset-vector sampling including four spatial coordinates of shot and receiver. On the basis of physical potential energy and force-balance principle, it analyzes the regularity coefficient of offset-vector sampling as a whole using potential function model and takes into account fold, offset-scalar and azimuth distribution factors. The combination of regularity coefficients of every bin can produce spatial continuity distribution of offset-vector sampling. Similar to symmetric sampling, this approach emphasizes the spatial relationships between adjacent bins rather than single bin attribute, since it aims to maintain the spatial continuity of the wavefield which allows the faithful reconstruction of the underlying continuous wavefield. Using this method, we can quantitatively compare spatial continuity distribution for different seismic acquisition geometries, and then choose the better acquisition scheme.

METHOD

The sampling of 3D seismic wavefield

The sampling of 3D seismic wavefield can be expressed as a 5D vector $W(t, x_s, y_s, x_r, y_r)$. Here, x_s, y_s, x_r and y_r are the shot and receiver coordinates. It would be prohibitively expensive to completely sample this 5D wavefield, as this would mean filling the whole survey area with a dense coverage of both shots and receivers (Vermeer, 1998). Changing the shot and receiver coordinates (x_s, y_s, x_r, y_r) to the midpoint and half-offset coordinates (x_m, y_m, x_h, y_h) (Figure 1), the 5D wavefield can be expressed as $W(t, x_m, y_m, x_h, y_h)$, where

$$\begin{aligned} x_m &= (x_r + x_s) / 2 \\ y_m &= (y_r + y_s) / 2 \\ x_h &= (x_r - x_s) / 2 \\ y_h &= (y_r - y_s) / 2 \end{aligned} \tag{1}$$

In every bin, the midpoint coordinates $M(x_m, y_m)$ are the same. Thus, the sampling of 3D seismic wavefield can be expressed as a 2D offset vector $H(x_h, y_h)$ (Figure 1).

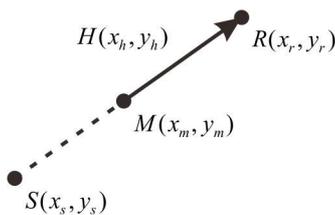


Figure 1: Schematic diagram of offset vector $H(x_h, y_h)$. Here, $S(x_s, y_s)$ and $R(x_r, y_r)$ are the shot and receiver coordinates, and $M(x_m, y_m)$ and $H(x_h, y_h)$ are the midpoint and half-offset coordinates.

On the basis of physical potential energy and force-balance principle, Hu et al. (2003) defines a potential function model. Using this potential function model, we define the regularity coefficient of the sampling of 2D point $H(x_h, y_h)$ as follow:

- (1) Define all the points $H_1, H_2, \dots,$ and H_n in 2D space as a set $S_0(H_1, H_2, \dots, H_n)$ (Figure 2).
- (2) As Figure 2 shown, copy the set of point S_0 along the positive and negative direction of x-axis and y-axis or the four diagonal directions, and get sets $S_1, S_2, \dots,$ and S_8 (Figure 2). Then define all the points in the sets $S_0, S_1, S_2, \dots,$ and S_8 as a set $S(H_1, H_2, \dots, H_{9n})$.
- (3) Summarize the potential energy from all the points in S_0 to that in S , and get the regularity coefficient C of the sampling:

$$C = \sum_{i=1}^n \sum_{j=1, j \neq i}^{9n} \frac{1}{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}} \tag{2}$$

The regularity coefficient C physically stands for the sum of potential energy with assumption of charge distribution at every points in S . The repulsive forces between all the objects in S_0 shove them away from each other (Figure 3a). At the same time, the repulsive forces between the objects in S_0 and the objects in S make the objects in S_0 get close with each other (Figure 3b). The electrostatic forces achieve balance when the electric charges are uniformly distributed on the space (Figure 3c). Accounting to the definition above, the smaller the regularity coefficient is, the more uniform the offset-vector distribution is. Using potential function model, we can analyze the regularity coefficient C of offset-vector sampling as a whole and take into account fold, offset-scalar and azimuth distribution factors (Figure 4).

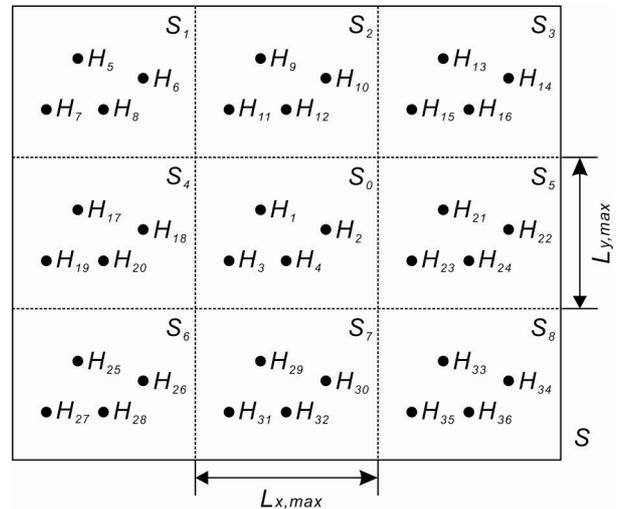


Figure 2: Copy the set of point S_0 along the positive and negative direction of x-axis and y-axis or the four diagonal directions, and get sets $S_1, S_2, \dots,$ and S_8 . Then define all the points in the sets $S_0, S_1, S_2, \dots,$ and S_8 as a set $S(H_1, H_2, \dots, H_{9n})$. Lx,max and Ly,max are the x-direction and y-direction components of maximum offset, respectively.

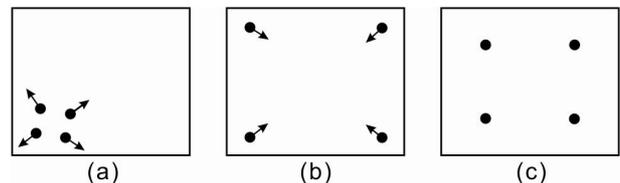


Figure 3: (a) The repulsive forces between the objects in S_0 shove them away from each other. (b) At the same time, the repulsive forces between the objects in S_0 and the objects in S make the objects in S_0 get close with each other. (c) The electrostatic forces achieve balance when the electric charges are uniformly distributed on the space.

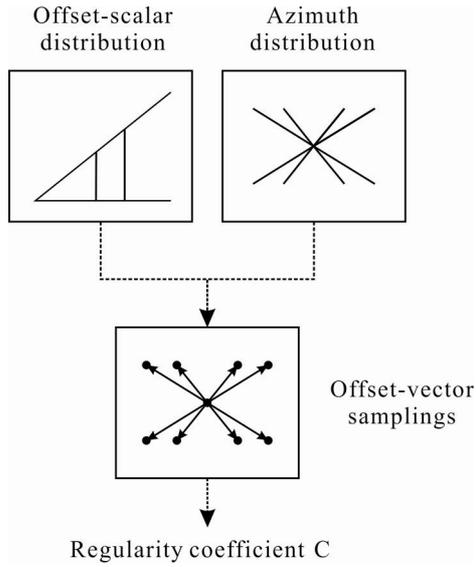


Figure 4: Schematic diagram of the regularity coefficient C of offset-vector samplings. It can analyse the performance of offset-vector sampling including offset scalar and azimuth factors.

Similar to the conventional CMP analysis, the regularity coefficient above is only undermined by offset-vector distribution of the earth's surface. However, it should also be influenced by a variety of factors, including the target depth, or how that velocity is distributed in the ray-path of seismic wave. We aim at analyzing the impact of acquisition geometry on the seismic imaging and therefore assume the velocity to be constant in the homogeneous medium setting. Then the sampling of 3D seismic wavefield which is expressed as a 7D vector $W(t, x_s, y_s, z_s, x_r, y_r, z_r)$, can be simplified to a 3D vector $H(x_h, y_h, z_h)$ for every bin, where

$$z_h = (z_r + z_s - 2z_f) / 2. \tag{3}$$

By introducing the depth component z_h into offset vector $H(x_h, y_h, z_h)$, this approach can analysis the spatial distribution of offset-vector sampling at different depths. Thus, it can be applied to the areas with irregular topography. Replacing CMP bin above by CRP bin, it can also be applied to the areas with more complex heterogeneous medium.

Spatial continuity distribution of offset-vector sampling

Combining regularity coefficients of every bin can produce spatial continuity distribution of offset-vector sampling including four or six spatial coordinates of shot and receiver. Similar to symmetric sampling, this approach emphasizes the spatial relationships between adjacent bins rather than single bin attribute, since it aims to maintain the spatial continuity of the wavefield which allows the faithful reconstruction of the underlying continuous wavefield.

For land data acquisition, the orthogonal geometry is the geometry of choice in general. However, there are situations in which it may be preferable to choose a different geometry including the slanted geometry, the zigzag geometry, and other target-oriented geometries (Campbell et al., 2002; Muerdter and Ratcliff, 2001). For marine streamer acquisition, the parallel geometry is the only choice. Once a nominal geometry has been decided upon, it may not be easy to realize the geometry without modifications. Especially for the marine streamer acquisition, the offset sampling in cross-line direction can become quite variable due to differential feathering (Vermeer, 1997). In that case, spatial continuity distribution of offset-vector sampling is of great importance to avoid irregular illumination of the subsurface. Using this method, we can quantitatively compare spatial continuity distribution for different seismic acquisition geometries in consideration of modifications in design and construction. It can be followed by the spatial resolution analysis (Berkhout et al., 2001; Volker et al., 2001; Van Veldhuizen et al., 2008; Vermeer, 1999; Gibson and Tzimeas, 2002) to provide a further estimate of the final image quality at a particular target area.

EXAMPLE

In this example, we analyze two 3D data acquisition geometries with different templates (Figure 5) using the concept of spatial continuity distribution of offset-vector sampling. All geometries are designed to have a square bin size of 50×50m and a fold of 40.

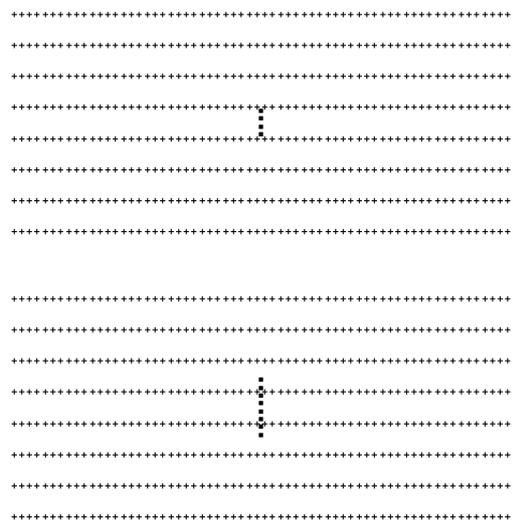


Figure 5: Schematic view of the templates of acquisition geometries. The two geometries are designed to have cross-line roll-along distances of 400m (top) and 800m (bottom), respectively. The square represents source and the cross represents detector.

The offset-vector sampling distributions for the two acquisition geometries are shown in Figure 6. They show how the cross-line roll-along distance affects the spatial continuity of the wavefield.

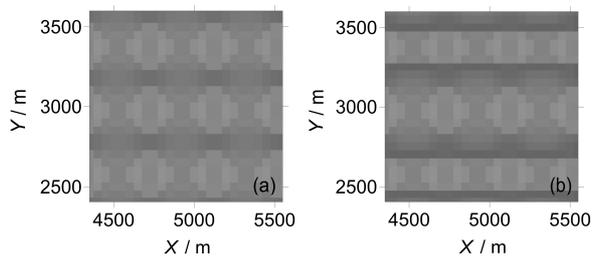


Figure 6: The offset-vector sampling distributions for the two acquisition geometry Schemes. The gray-scale values indicate offset-vector regularity coefficients on a linear scale.

CONCLUSIONS

In this paper, we propose a new method for quantitatively evaluating the continuity of offset-vector sampling including four spatial coordinates of shot and receiver. On the basis of physical potential energy and force-balance principle, it analyzes the regularity coefficient of offset-vector sampling as a whole using potential function model and takes into account fold, offset-scalar and azimuth distribution factors. The combination of regularity coefficients of every bin can produce spatial continuity distribution of offset-vector sampling. Similar to symmetric sampling, this approach emphasizes the spatial relationships between adjacent bins rather than single bin attribute, since it aims to maintain the spatial continuity of the wavefield which allows the faithful reconstruction of the underlying continuous wavefield. Using this method, we can quantitatively compare spatial continuity distribution for different seismic acquisition geometries, and then choose the better acquisition scheme.

REFERENCES

Berkhout, A. J., L. Ongkicheong, A. W. F. Volker, and G. Blacquiere, 2001, Comprehensive assessment of seismic acquisition geometry by focal beams—Part I: Theoretical considerations. *Geophysics*, 66, 911-917.

Campbell, S., W. B. Pramik, and B. Cafarelli, 2002, Comparative ray-based illumination analysis: 72nd Annual International Meeting, SEG, Expanded Abstracts, 41-44.

Cordsen, A, M. Galbraith, and J. Peirce, 2000, Planning land 3-D seismic surveys: Society of Exploration Geophysicists.

Gibson, R. L. and C. Tzimeas, 2002, Quantitative measures of image resolution for seismic survey design: *Geophysics*, 67, 1844-1852.

Hu, D. H., D. H. Li, Z. X. Wang, 2003, Potential Function Model of Uniformity Measurement (in Chinese): *Acta Mathematica Scientia*, 23, 607-612.

Muerdter, D., and D. Ratcliff, 2001, Understanding subsalt illumination through ray-trace modeling, Part 1: Simple 2D salt models: *The Leading Edge*, 20, 578-595.

Slawson, S. E., K. D. Grove, and G. W. Fischer, 1994, Model-based 3D seismic acquisition design: 64th Annual International Meeting, SEG, Expanded Abstracts, 919-920.

Stone, D. G., 1994, Designing seismic surveys in two and threedimensions: Society of Exploration Geophysicists.

Van Veldhuizen, E. J., G. Blacquiere, and A. J. Berkhout, 2008, Acquisition geometry analysis in complex 3D media: *Geophysics*, 73, Q43-Q58.

Vermeer, G. J. O., 1997, Streamers versus stationary receivers: Offshore Technology Conference, paper OTC8314.

Vermeer, G. J. O., 1998, 3-D symmetric sampling: *Geophysics*, 63, 1629-1647.

Vermeer, G. J. O., 1999, Factors affecting spatial resolution: *Geophysics*, 64, 942-953.

Vermeer, G. J. O., 2002, 3-D seismic survey design: Society of Exploration Geophysicists.

Volker, A. W. F., G. Blacquiere, A. J. Berkhout, and L. Ongkicheong, 2001, Comprehensive assessment of seismic acquisition geometry by focal beams—Part II: Practical aspects and examples: *Geophysics*, 66, 918-931.