Interpolation of multi-line 2-D seismic data

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Abstract

3-D seismic survey is recognized as a very powerful exploration tool and the usage is widely made to obtain clearer subsurface images. However, there is the case in which the acquisition of 3-D seismic data is not allowed economically or in exploration strategy. In such a case only existing 2-D data give the subsurface information. However, the interpretation of multi-line 2-D seismic data is always ambiguous under the complex geological structure. The main reason is that the sideswipe reflections are not separated on single 2-D seismic data. The only way to improve the interpretation accuracy is that the sideswipe energy contained in multi-line 2-D data set is located in the correct reflection position and shapes the reflector image by means of 3-D pre-stack depth migration (PSDM).

Our final goal of the study is to obtain a 3-D subsurface image from multi-line 2-D seismic data by means of 3-D PSDM. The critical issue of the approach is that the subsurface spatial sampling is too sparse to obtain a meaningful PSDM image. Therefore, the elaborated interpretation technique is necessary to compensate the lack of spatial sampling.

In this paper we will discuss an interpolation technique to produce a pseudo 3-D data set from sparse multi-line 2-D data using $t$-$x$-$y$ domain operator.

1 Introduction

3-D seismic survey is a very powerful exploration technique, but it is not easy to use because of survey cost problems. To overcome this problem we investigated an interpolation methodology using 2-D seismic data. Our study proposes a method to produce pseudo 3-D data from existing multi-line 2-D seismic data. 3-D structure affects 2-D images. Sideswipes often lead wrong interpretation. Conventional 2-D imaging could not separate the energy. To improve the interpretation accuracy, the energy must be removed. We are trying to produce 3-D image volume by means of 3-D pre-stack depth
In this section we discuss a method of interpolation of the seismic data.

**Methodology**

We begin by discussing some general properties of the interpolation problem. The problem is to find a smooth function that interpolates a given set of data points. The method we propose is based on the following formula:

\[
\frac{\int_{-\infty}^{\infty} \left( \frac{\partial}{\partial \xi} \mathcal{F} \right) e^{i\xi x} \, d\xi}{\left( \frac{\partial}{\partial \xi} \mathcal{F} \right) e^{i\xi x}} = \frac{\int_{-\infty}^{\infty} \left( \frac{\partial}{\partial \xi} \mathcal{F} \right) e^{i\xi x} \, d\xi}{\mathcal{F}}
\]

This formula is derived from the convolution of the interpolated function with a window function. The interpolated function is defined as the convolution of the window function with the observed data.

In this paper, we will discuss the interpolation technique using 3-D h-x-y data.

However, the technique requires 3-D Fourier transform of data sets and it may be costly. Therefore, they require 3-D Fourier transform of data sets and implementation of the interpolation operation. It is also easy to implement the technique using 3-D h-x-y data.

The critical issue of this approach is the computational cost of the convolution operation. The method we propose is based on the following formula:

\[
\mathbf{f}_I = \mathbf{f}_I \ast \mathbf{w}_{\text{int}}
\]

where \( \mathbf{f}_I \) is the interpolated data set, \( \mathbf{w}_{\text{int}} \) is the interpolating weighting function, and \( \ast \) denotes the convolution operation.
In this equation, both \( x \) and \( y \) are distances between receiver points of sampled data and interpolated data position, and \( t \) means time of sampling. There are five parameters in the equation (1), \( f_0 \) is the maximum frequency of seismic data, \( x_0 \) and \( y_0 \) define the influenced area of weighting-function, \( c_1 \) and \( c_2 \) are determined from interpreted dip in \( x \) and \( y \) domain. We assume that operator shape is expressed as a sinc function band-limited between \(-f_0\) and \( f_0 \) in time domain and reflection boundaries expand in an area defined as the gaussian distribution that has standard deviations \( x_0 \) and \( y_0 \). In addition, the structural parameters, \( c_1 \) and \( c_2 \) that means structural dip of \( x \) and \( y \) domain (\( dt/dx, dt/dy \)).

The weighting-function can be changed in time and space if the five parameters are given as functions of time and space. We use common offset gathers in spite of shot gathers. The reason is to be able to use structural interpretation directly in determining the weighting function. At an arbitrary point, the interpolated trace is obtained by summing of calculating the weighting-function for every input traces.

3 Synthetic example

We applied this interpolation method to a synthetic data set. The data set is generated from a dipping boundary model. The boundary has both in-line and cross-line dip those are \(-5^\circ\) and \(5^\circ\), and the depth at \((0, 0)\) is 1000m. The P-wave velocity of upper medium is 2000m/s and the lower medium is 1800m/s (Fig.2). We choose this velocity structure since there does not exist over critical reflections.

Fig.3 shows location of sources and receivers of the synthetic data and the interpolated data. Line-s1 and Line-s2 show the pseudo survey lines, which have 150m shot and receiver offset and \(5^\circ\) of feathering. Line-1, 2 and 3 show interpolated lines. The distance between lines is shortened from 500m to 125m. Fig.4 shows synthetic data on Line-s1 and Line-s2, there are \(32\) shots \(\times\) \(2\) lines data. The sampling interval time is 1msec and a wavelet is Ricker wavelet whose peak frequency is 100Hz.

In Fig.5, 3 lines (Line-1, Line-2 and Line-3) are interpolated from above 2 lines. This example shows that the proposed method can produce a reasonable pseudo line data. The future work is to consider time- and space-variant operator for complex structure.
4 Conclusion

In this study, it is suggested that interpolation method using t-x-y operator to produce pseudo seismic traces from existing multi-line 2-D seismic data. In simple synthetic example, this method shows good results. We will apply this method more complex case or/and field data and consider more detail of this method in future.

We believe this interpolation method helps us to acquire better 3-D image volume from multi-line 2-D seismic data by means of 3-D PSDM.

Fig. 2: Synthetic example: one diped boundary model. P-wave velocity of the upper medium is 2000 m/s and the medium is 1800 m/s. In-line dip is $-5^\circ$ and cross-line dip is $5^\circ$.

References


Figs. 4-6: Synthetic data on Line-1 and Line-2.

Fig. 7: Line-1, Line-2, and Line-3 are interpolated lines.

Fig. 8: Line-1 and Line-2 are surveyed lines that have sampled data, and...
Fig. 5: Comparison of interpolated data and true data on Line-1, Line-2 and Line-3.