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Calculation of grey level co-occurrence matrix-based seismic attributes in three dimensions

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A B S T R A C T

Seismic interpretation can be supported by seismic attribute analysis. Common seismic attributes use mathematical relationships based on the geometry and the physical properties of the subsurface to reveal features of interest. But they are mostly not capable of describing the spatial arrangement of depositional facies or reservoir properties. Textural attributes such as the grey level co-occurrence matrix (GLCM) and its derived attributes are able to describe the spatial dependencies of seismic facies. The GLCM – primary used for 2D data – is a measure of how often different combinations of pixel brightness values occur in an image. We present in this paper a workflow for full three-dimensional calculation of GLCM-based seismic attributes that also consider the structural dip of the seismic data. In our GLCM workflow we consider all 13 possible space directions to determine GLCM-based attributes. The developed workflow is applied onto various seismic datasets and the results of GLCM calculation are compared to common seismic attributes such as coherence.

1. Introduction

Seismic attribute analysis is a common tool in the field of seismic interpretation. The purpose of seismic attribute analysis is to spatially delineate reservoirs by identifying structural and depositional features. There are lots of different ways of calculating seismic attributes whereby the calculation of texture attributes is one of the promising possibilities for differentiation of channel-fill. Over the last three decades seismic attribute analysis has evolved from complex trace attributes (Taner et al., 1979), to coherence cubes (Bahorich and Farmer, 1995), to curvature (e.g. Marfurt and Kirlin, 2000), spectral decomposition (e.g. Partyka et al., 1999), and many more. All these methods use mathematical relationships based on the geometry and the physical properties of the subsurface to illuminate geological features of interest. In contrast to that textural attributes describe the spatial arrangement of constituents/neighboring amplitudes/rock units/depositional facies/reservoir properties (Gao, 2011). By analyzing seismic amplitude and waveform any human interpreter follows unintentionally the same concept. Amongst the many methods available for texture analysis we have chosen the statistical texture classification method of the grey level co-occurrence matrix (Haralick et al., 1973) and its derived attributes to incorporate a semi-automated description of the spatial arrangement of seismic facies. The grey level co-occurrence matrix (GLCM) was primarily designed for texture classification of two-dimensional images. To calculate GLCM attributes for three-dimensional seismic data it is necessary to adapt the methodology to work in 3D space. Previous works on 3D GLCM calculation use 2D GLCM calculation in various directions and combine the results of these calculations to form a pseudo-3D GLCM attribute cube (e.g. Gao, 2011; De Matos et al., 2011). In this work we describe a workflow for full 3D calculation of GLCM that also incorporates the structural dip of the seismic data. Our workflow measures the co-occurrence of pixel-pairs in all possible spatial directions within a defined analysis window. The results of our 3D GLCM calculation are compared to coherence cubes.

2. The grey level co-occurrence matrix

The grey level co-occurrence matrix (GLCM) and its derived attributes are tools for image classification that were initially described by Haralick et al. (1973). Principally, the GLCM is a measure of how often different combinations of pixel brightness values occur in an image. It is a method widely used in image classification of satellite images (e.g. Franklin et al., 2001; Tsai et al., 2007), sea-ice images (e.g. Soh and Tsatsoulis, 1999; Maillard et al., 2005), magnetic resonance and computed tomography images (e.g. Kovalev et al., 2001; Zizzari et al., 2001), and many others. Most of these GLCM applications are for classification of 2D images solely. The application of GLCM for seismic data has been a minor topic in comparison to common seismic attributes such as coherence, curvature or spectral decomposition. Today, a high

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percentage of the available seismic data is 3D seismic. Therefore, it is important for the classification of seismic data to adapt the GLCM calculation to work in the three-dimensional space. Few authors have described the application of GLCM for 3D seismic data with various approaches to this topic (Vinther et al., 1996; Gao, 1999, 2003, 2007, 2008a, 2008b, 2009, 2011; West et al., 2002; Chopra and Alexeev, 2005, 2006a, 2006b; Yenugu et al., 2010; De Matos et al., 2011; Eichkitz et al., 2012b).

The GLCM, as mentioned earlier, is a measure of how often different combinations of neighboring pixel values occur. To describe the methodology behind GLCM calculations it is necessary to extend the previous statement. For a 2D image the immediate neighboring pixels can be in four different directions (0°, 45°, 90°, and 135°). For the calculation of 2D GLCM the following equation is used:

$$M(i,j) = \sum_{x=1}^{X}\sum_{y=1}^{Y}\begin{cases}1, & G(x,y)=i \text{ AND } G(x+dx,y+dy)=j\\ 0, & G(x,y)\neq i \text{ OR } G(x+dx,y+dy)\neq j\end{cases} \quad (1)$$

where i and j vary from 1 to N_g (number of grey levels).

In this equation $G(x,y)$ are the center sample points and $G(x+dx, y+dy)$ are the neighboring sample points. Usually, the distance between center and neighboring samples is one, but greater distances can also be taken for the calculation.

It is, in principal also possible to combine the four principal directions to form an average GLCM. By this approach the spatial variations can be eliminated to a certain degree (Gao, 2007). In the case of 3D data the number of possible directions increases to 13. In Fig. 1a a simple Rubik's cube is taken to explain the 13 possible directions for a 3D dataset. This Rubik's cube is build-up of 27 small cubes. The small cube in the center (the turning point in a Rubik's cube) is the point of interest for which the calculations are performed. This center point is surrounded by 26 neighboring cubes. If we now take the center point and draw lines form it to all neighboring cubes, we get 13 directions on which the neighboring samples are placed (see Fig. 1c). The 3D case implies a modification of the above given equation. According to Tsai et al. (2007) and Lai and Tsai (2008) the 2D equation can simply be adapted to the following:

$$M(i,j) = \sum_{x=1}^{X}\sum_{y=1}^{Y}\sum_{z=1}^{Z}\begin{cases}1, & G(x,y,z)=i \text{ AND } G(x+dx,y+dy,z+dz)=j\\ 0, & G(x,y,z)\neq i \text{ OR } G(x+dx,y+dy,z+dz)\neq j\end{cases} \quad (2)$$

With this approach it is possible to calculate full 3D grey level co-occurrence matrices.

Similar to the 2D case, it is possible to calculate the GLCM in single directions, to combine several directions, or to calculate an average GLCM. Previous works on 3D GLCM calculation use 2D GLCM calculations in various directions and combine the results of these calculations to form a pseudo-3D GLCM attribute cube (e.g. Gao, 2011; De Matos et al., 2011). Our algorithm allows calculation in a single direction, the combined calculation of inline, crossline, time-/depth-slices, or in the two diagonal directions, or the average of all 13 directions.

Based on the grey level co-occurrence matrix, it is possible to calculate several attributes. Haralick et al. (1973), in their work, describe 14 attributes that can be calculated from the GLCM. In literature a few more attributes based on the GLCM have been developed (e.g. Soh and Tsatsoulis, 1999; Wang et al., 2010). For the calculation of any of these GLCM-based attributes it is necessary to normalize the GLCM to generate a kind of probability matrix. This is done by dividing each matrix entry by the sum of all entries. The different GLCM-based attributes can be divided into three general groups. The first group is the contrast group and includes measurements such as contrast (Eq. (3)) and homogeneity

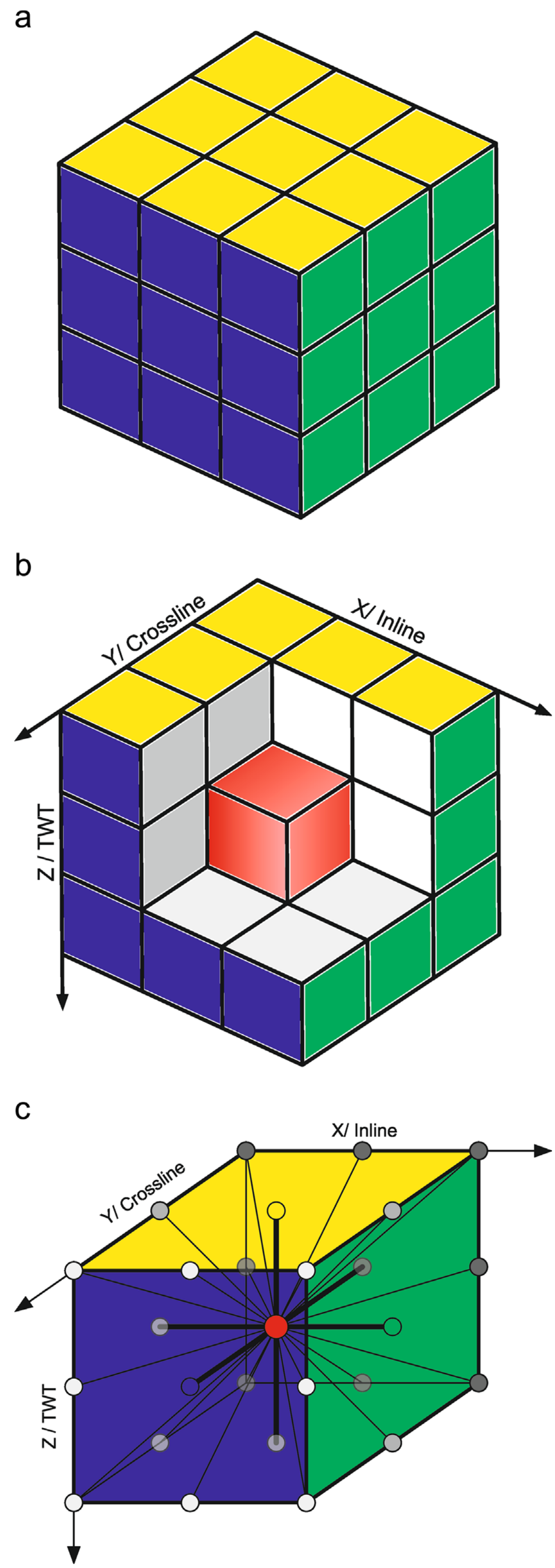

Fig. 1. The number of principal neighbors for one sample point can be best explained by looking at a Rubik's cube (a). The center of the Rubik's cube (core mechanism for rotating the cube, red box in (b)) has in total 26 neighboring boxes (including diagonal neighbors). These boxes are aligned in 13 possible directions. Similar to that, a sample point within a seismic subvolume has 26 neighbors aligned in 13 directions (c). In the developed workflow it is possible to calculate the GLCM along single directions, along combinations of directions (e.g. inline direction, crossline direction, …), or all directions can be calculated at once. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)