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Calculation of bedding angles inclination from drill core digital images

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Abstract

In this paper, we describe a new technique for the automatic orientation of bedding in drill core from digital images. Images are planar pictures of the drill core, and we show that it is possible to determine layer orientation without rotating the core on the full circumference. More precisely, we show that angle information can be extracted by applying image processing and a mathematical description of bedding trace on the core. The angles' estimation is done by adapting the Hough transform technique. This work is part of a more important project of our laboratory that aims to develop a drill core image analysis software.

1. Introduction

In the context of drill core studying (historical geology, oil and mining prospecting, etc), for a lot of geological applications, sedimentary strata dip appears as one of the main parameters to determine.

Several methods have been developed for that purpose. In [7] the authors use a transparent template that allows simultaneous measurement of two angles. Unrolling the image core in 2D will show the sine wave representing the border of strata, and the amplitude of sine wave allows to determine the dip angle orientation [1]. Another way is to manually measure the orientations on images provided by OPTV (Optical Televiewer) technique [6].

In this paper, we present an innovative method to access dip information. This method combines two complementary approaches : pattern recognition and mathematical modelling. In a first step, these two approaches are applied to a theoretical case: a cylinder (the core) cut by an inclined plane (the stratification). After filter processing, image analysis allows to position the external borders of geological strata on a real object. By means of a mathematical calculation, Hough transform enables us to determine, according to a Cartesian coordinate system Oxyz, plunging parameters (angles and depth) for different strata identified by image processing. These parameters correspond to the layers' dip, more or less some angular variables. Beyond mathematical developments presented here, a simple change in the coordinate system will permit to express dip in a geographical coordinate system, in the context of geological applications.

In the following sections, we present the developed approach. In the second section, we define the angle convention for drill core, and we infer the elliptical equation depending on the defined angles. Then, we give the the technique of angle calculation by Hough Transform. In section 3, we present the procedure of core image processing. In sections 4 and 5, we show the results obtained respectively on simulated core image and on real core image. Section 6 deals with conclusion and perspectives.

2. Description of our approach

The drill core used here is made of different layers (strata). The considered orientation is the position between the layer and the horizontal plane. This orientation is completely specified by two angles α and β with respect to a perspective convention (see Figure 1). This angles' estimation is based on image core analysis. For that purpose, we used and adapted a well-known technique: the Hough transfom.

2.1. Drill core angle convention

Due to the drill core cylindrical shape, all planes intersecting the drill core have an elliptical cross-section as shown on Figure 1. Here, we will suppose that the core is oriented, meaning that during the drilling process, an orientation line has been drawn on the core. This line indicates, for example, the North direction. For unoriented or partially oriented drill cores, different techniques can be employed in order to reorient the core (multiple drill holes, comparison between electrical and digital images etc.). But this case is beyond the scope of this paper.

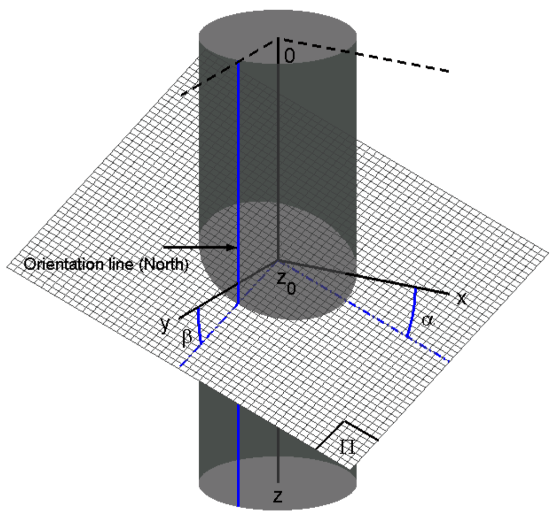


Figure 1 : Coordinate system and angles definition.

Measurement conventions used in this paper are the following:

- Coordinate system Oxyz: the core is oriented in this system as follows: z axis is the drilling core axis (downmetres), and Oxy is a plane normal to the core axis; y axis is oriented in the north direction (reference line), and x axis is such that Oxyz forms a right-handed Cartesian coordinate system.
- z_0 is the intersection between plane Π and z axis
- Angle α: angle between y axis and the projection of y on plane Π.
- Angle β: angle between x axis and the projection of x on plane Π.

2.2. Mathematical expression of the elliptical cross-section

During the image acquisition, the core will be oriented so that the orientation line faces the camera. In other words, the camera lens axis maps with y axis. The cross section between a tilted plane and a cylinder is an ellipse (see Figure 2). The mathematical expression of this ellipse can be calculated as follows:

Plane: $$z = x \cdot \tan(\alpha) + y \cdot \tan(\beta) + z_0 \quad (1)$$

Cylinder: $$y = \pm R \cdot \sqrt{1 - \frac{x^2}{R^2}}, \quad x \in [-R, R] \quad (2)$$

Replacing (2) in (1), we obtain the ellipse equation in the (x,z) plane:

$$z = x \times \tan(\alpha) \pm R \times \sqrt{1 - \frac{x^2}{R^2}} \times \tan(\beta) + z_0 \quad (3)$$

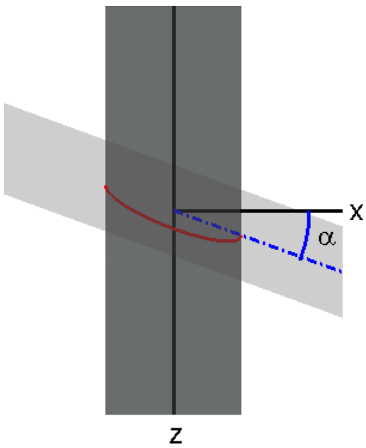


Figure 2 : Projection of the elliptic curve intersection on Oxz

The angles estimation could be performed by picking up 3 points, because the analytical expression of borders is known. Nevertheless, this method is inefficient on natural core images which are generally corrupted by noise and deformations.

2.3. Angles estimation by Hough transform

The Hough transform [5], [3] provides a powerful and robust technique for detecting the geometrical form of a pre-defined shape. This technique is widely used to isolate curves of a given shape in an image. The classical Hough transform [4] requires the curve to be specified in some parametric form. Therefore it is most commonly used to detect regular curves such as lines, circles, and ellipses. We have chosen this technique because its advantages are the gap tolerance in curves and its robustness to noise. The pixels lying on a curve do not need to be all contiguous.

The Hough transform principle is to project the image space into a parameter space that represents the target shape. For an elliptic form, for example, five parameters are unknown and must be estimated: center of ellipse (2 parameters), minor axis, major axis and orientation.

In our case, we do not need to calculate all the parameters of the elliptic shape, but only its inclination, in relation to the horizontal plane as shown in Figure 2. Then, we consider the parameter space as a 3 dimensional space, α and β angles, and z_0 coordinate being the unknown parameters. For implementation purpose, we use a three dimensional accumulator $A(\alpha, \beta, z_0)$ to represent the quantity (α, β, z_0). Note that the core image used here is a two dimensional image. Thus, we only get a part of the elliptic form. However, and according to the angle convention assumed in section 2.2, this part of the ellipse is oriented for a positive y. The equation (3) becomes :

$$z = x \times \tan(\alpha) + R \times \sqrt{1 - \frac{x^2}{R^2}} \times \tan(\beta) + z_0 \quad (4)$$

If a point (x_i, z_i) belongs to this curve, then we have :

$$z_i = x_i \times \tan(\alpha) + R \times \sqrt{1 - \frac{x_i^2}{R^2}} \times \tan(\beta) + z_0 \quad (5)$$

This equation defines the values of (α, β, z_0) so that the curve passes through the point (x_i, z_i). As it is well-known in Hough transform, if values of (α, β, z_0) are plotted as graph image, for a given point, then curve is obtained (see Figure 5). However, points belonging to the given elliptic curve are associated by this transform to curves which intersect in one point since they share common (α, β, z_0).

3. Core-processing procedure

Several processing steps on the drill core image are necessary to estimate the angles inclination of strata. Those steps are described below:

1. **Gray level image acquisition**. We used a digital camera with a ¼-inch CCD sensor combined with a 10× zoom Carl Zeiss lens and a video monitor. The images were taken with a normal angle of incidence in white light, using a wide field of vision to detect layers (Figure 3).

Figure 3: Raw image of core sample.

2. **Strata segmentation**. The image is segmented on strata by using the wavelet transform [8]. Once the strata are detected, further image processing is necessary to locate edges.
3. **Edge detection and labeling**. For edge detection, we simply use an horizontal gradient, because the strata are vertically oriented. As known, the gradient operator is very noisy. A post-processing step is necessary to eliminate false edges detected due to noise. To make the maxima detection easier on the HT parameters space, we proceed to a labeling phase of edges. So, each edge is isolated and correspond to one maximum.
4. **Angles calculation**. We used the adapted Hough transform on elliptic shapes to estimate the angles (α and β) and depth z_0 set by equation (3) in section 2.2.

In practice, we sampled the parameters (α, β, z_0), and we varied α and β between 0 and $\pi/3$. A condition that is required on parameter z_0 is that z_0 must be in [0,s] where s is the length of the core image.

For each element corresponding to a particular value of α, β and z_0, our representation of space (α, β, z_0) is now a simple three dimensional array called accumulator. For each point (x_i, z_i) in the image we increment all accumulator cells such as the cell coordinates (α, β, z_0) satisfy the equation (5). After all points have been visited, we detect the maximum value corresponding to cell where the greatest amount of points occurs in the curve.

4. Simulation

In this section, we have tested our algorithm on a simulated core image to check its performance under ideal conditions. Having the mathematical equations of strata edges, we can generate a core image depending on parameters z_0, α and β.

The core radius and its length are respectively equal to 92 and 631 pixels. The core is made of 3 strata, thus we have 2 intersections with the following parameters:

Table 1: parameters for simulated curves in Figure 1

Parameter	Edge 1	Edge 2
z (pixels)	200	400
α (°)	15	25
β (°)	20	30

The simulated core is shown on Figure 4.

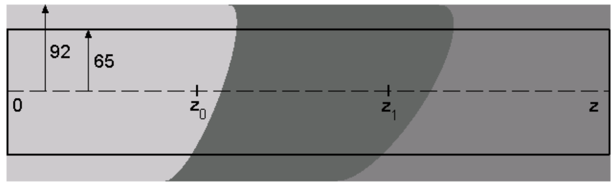
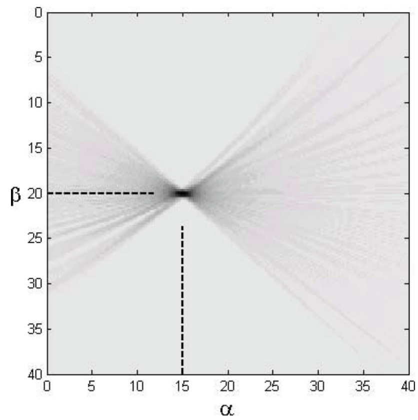


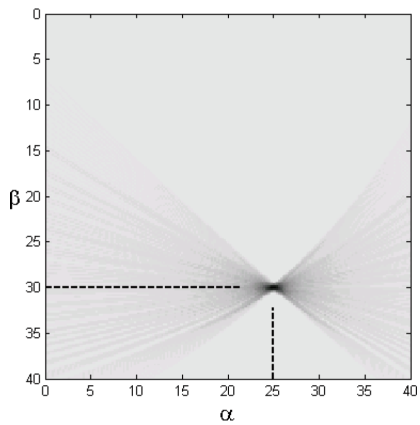
Figure 4 : Example of simulated core image

Because of border effect on core picture, we selected an area (see Figure 4). The new image dimensions are 131×631 pixels.

Each edge is then sent to the Hough module which performs a calculation on a uniformly spaced array grid (0.2°). As we sent one edge at a time, the depth and angles information can be obtained by detecting the global maximum value of the Hough matrix. Figure 5a shows the (α, β) set for z_0=200 and Figure 5b for z_0=400.



a. Maximum value corresponding to the first curve



b. Maximum value for the second curve

Figure 5 : Image visualization of the accumulator A for the simulated core

Figure 6 : Curves reconstruction from estimated parameters by Hough Transform

5. Application on real drill core images

We apply our algorithm on real core image displayed in Figure 3. After performing all the processing steps detailed in section 3, we obtain the strata segmentation result in Figure 7, and the result of edge detection in Figure 8. For illustration purpose, the Figure 9 shows the result of Hough transform performed on the isolated red curve (see Figure 8).

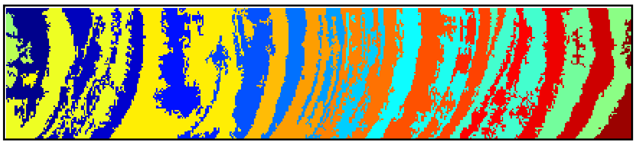


Figure 7 : Layer segmentation

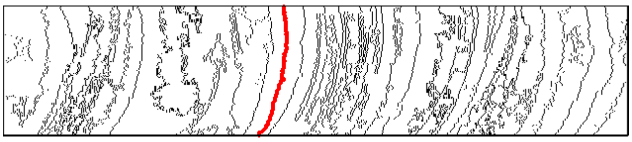


Figure 8 : Edge detection

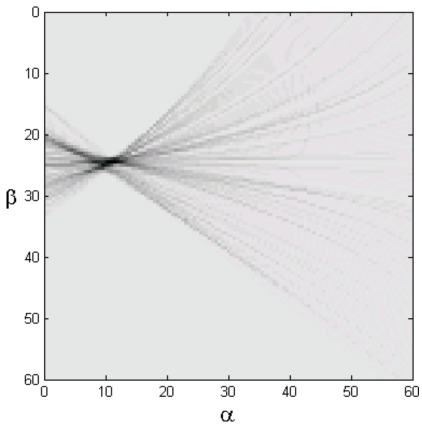
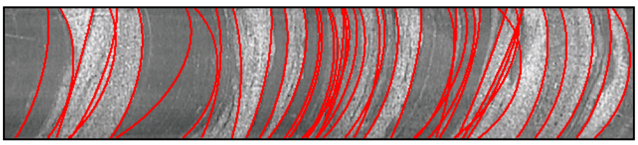
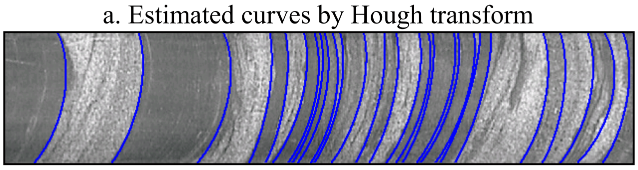


Figure 9 : Hough space parameters for red edge in Figure 8

We repeat the last process on all labeled edges. For each edge, we obtain the corresponding set of parameters (α, β, z_0). In Figure 10a, we display the estimated edges by using the curves equation (5). With the expert geologist, we pick up manually some points on each edge strata. We calculate, then, the corresponding angles by using directly the equation (5) (see Figure 10b).



a. Estimated curves by Hough transform



b. Estimated curves Visually

Figure 10 : Real core images

As we can see in the image a, the automatic detection extracts the majority of edges seen by geologist expert. In addition, other edges are extracted and some of them can be important for the geologist. But, the process also generate false edges due to segmentation strata.

Globally, the result is satisfactory for the geologist expert. The interesting parameters for this current analysis is the average angles value of core strata. So we calculate the average angles respectively for both images a and b, and values are shown in Table 2.

Table 2 : Angles average of curves

Angles estimation	on Figure 10a	on Figure 10b
α (°)	12.4	14
β (°)	26	27.8

6. Conclusions and perspectives

In this paper, we proposed a fully automated approach allowing to finally provide dip parameters from a raw core image. The results are satisfactory. On one hand, most of strata have been extracted and on the other hand, the average calculated angle is very closed to the one estimated by the geologist. The method can be improved by adopting a strategy of maxima detection in the Hough transform parameters space. This will allow to apply the Hough transform in one pass on the whole edges image.

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