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Extraction of diamond grain topography from diamond tool surface using 3D surface measurement coupled with image analysis

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ABSTRACT

Characterization of protruded diamond grains in a diamond tool is essential to explain the variation in its machining performance. This paper proposes a method for extraction of diamond grains and reconstruction of their topography from an electroplated diamond bit, using the topographic data and optical micrographs acquired with a confocal laser microscope. Otsu method, mean shift method and texture based method were selected for segmentation of the optical micrographs and their performance was evaluated. Experiment results show that texture based method can satisfactorily extract protruded diamond grains; its result was used to reconstruct diamond grain topography successfully.

1. Introduction

Impregnated diamond cutting tools, such as saw blade, core drill bit and wire saw, are widely used to machine the most difficult-to-cut materials (reinforced concrete, granite, engineering ceramics, etc.). Diamond cutting process is the combination of lots of micro-machining processes performed by individual diamond grain in the tool [1]. The size, shape and distribution of protruded diamond grains have significant effects on the tool cutting performance. Therefore, there are considerable interests in measuring topographic information to explain the variation in cutting performance and to understand the wear mechanism of diamond grains and bond.

In the literature, many attempts have been made to characterize the topography of the work face of diamond tools by either contact or non-contact measurement methods. For example, Somicronic Surfascan 3D stylus-based measuring instrument [2], Talyscan 150 stylus system [3] and LH-65 coordinates measuring machine [4] were employed to conduct the intellectualized measurement of grain protrusion topography on grinding wheel surface. Adopted non-contact measurement approaches include auto-focusing system [5], white light interferometer [6] and confocal laser scanning microscope [7], etc. With all these methods, valuable information about protruded diamond grains can be obtained. In the data processing procedure of these measurements, the identification of diamond grains from topographic data is a key step, which determines the accuracy of obtained topographic information. Unfortunately, diamond grains were usually separated from the bond based on height information in most researches [2,3,5,8], which cannot always ensure reliable detection of diamond grains owing to the existence of bond tails (the bond that has not worn away and follows a protruded diamond). As for the method to extract diamond grains based on the difference in reflectivity between diamond grain and bond [9], it is hard to satisfy its assumption that all crystal surfaces of a protruded diamond grain reflect light without great difference. Therefore, it will be valuable to find an accurate method for extraction of protruded diamond grains. To distinguish diamond grains from their surrounding bond with image analysis technique seems like a good idea [1,10], although there is much room for improvement.

This paper proposes a method for accurately reconstructing the topography of protruded diamond grains by using 3D laser measurement and image analysis techniques. The 3D topographic data and optical micrographs of the work surface of an electroplated diamond bit used for rock drilling were acquired with a confocal laser microscope. Otsu method, mean shift method and texture based method were selected for segmentation of the optical micrographs; evaluation of their segmentation performance was

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performed based on precision and recall ratios; the segmentation result was then fused with the 3D coordinate data to reconstruct the topography of protruded diamond grains.

2. Methodology

To reconstruct the topography of protruded diamond grain, we need the 3D coordinates of its exposed surfaces. Our method includes following steps: acquire the 3D coordinates and the micrograph of tool work surface; segment the micrograph to localize diamond grain in the image; with the *XY* coordinates transformed from the location of detected diamond in the image, find corresponding *Z* coordinate data for diamond surface.

2.1. 3D topography measurement and specimen

A confocal laser microscope (Keyence VK-X110) was used to observe protruded diamond grains and measure 3D topographic data. This microscope is capable of capturing an optical micrograph and measuring 3D topographic data simultaneously. A used electroplated diamond bit with an outside diameter of 41 mm was selected as a specimen. The average diameter of diamond grains is 385 um (40/45#) and the bond is nickel electrodeposit. Every micrograph has a resolution of 1024 by 768 pixels, corresponding to an area of 1400 by 1000 μm^2. Based on the degree of wear of diamond grains, four types of images (newly protruded diamond, slightly worn diamond, moderately worn diamond and severely worn diamond) were found out in the micrographs and then cropped for the evaluation of segmentation algorithms, as shown in Fig. 1. We expect that there is a segmentation method adequate for all the four types of images.

2.2. Image segmentation methods

To extract diamond grains as accurately as possible from the tool surface micrograph is the emphasis of this work. In the past few decades, a lot of image segmentation algorithms have been proposed. However, there is no perfect method that is applicable for all types of digital image, since most approaches were developed for a specific application using specific constraints [11]. In this paper, we will compare three different segmentation techniques, Otsu thresholding method, mean shift-based segmentation algorithm and texture based segmentation method, in order to find a better segmentation algorithm for tool surface micrograph acquired with confocal laser microscopy. Otsu method is selected for the reason that it is a simple, parameter free, yet effective global automatic thresholding method and has been adopted by Jiang [10]. Mean shift-based method is chosen as it is generally effective and has become widely used in image analysis [12]. Using mean shift method, we fixed spatial bandwidth at 11, range bandwidth at 10 and minimum region at 3000. As the mean shift algorithm partitions the image into several segments rather than separates a diamond grain from the background, we have to manually binarize its result. Finally, diamond grain and bond visually have different surface textures, so it is possible that texture based method is able to obtain good results [13]. In this paper, we select entropy to characterize the texture of diamond grain and bond. Entropy is a statistical measure of randomness within a neighborhood (here, a 9-by-9 square) around the corresponding pixel. We binarized the entropy images at the threshold of about 0.65, which was selected with reference to Otsu threshold and improved through experiments.

To evaluate the three segmentation methods quantitatively, we use precision and recall ratios as measures of segmentation quality. Precision and recall are defined, respectively, as:

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \quad (1)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \quad (2)$$

where, TP (True Positive) is the number of correct predication that a pixel belongs to diamond grain; FP (False Positive) is the number of incorrect predictions that a pixel belongs to diamond grain; FN is the number of incorrect predictions that a pixel does not belong to diamond grain.

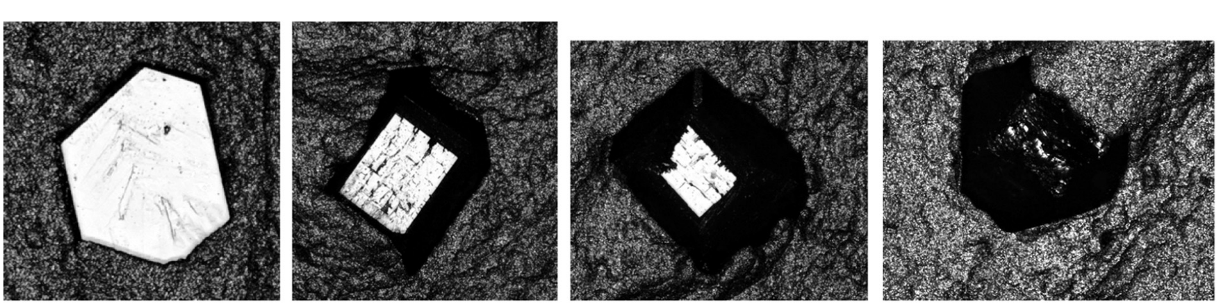
2.3. Reconstruction of diamond topography

Extraction of diamond grain in tool surface micrograph delineates the region of diamond grain in the image. To utilize image segmentation result in the localization of diamond grain in the 3D coordinates, we interpolate the 3D topography data over a uniform grid with the same size as the micrograph resolution. Since the 3D topography data and the micrograph correspond to the same region, the subscripts of *X*-axis coordinates and *Y*-axis coordinates of the diamond grain in the interpolated 3D coordinates matrix must be same to those of the pixels marked as diamond grain in the image. Thus, using the subscripts of pixels in the image as query points, we can obtain the *X*-axis, *Y*-axis and *Z*-axis coordinates of the diamond grain. The topography of protruded diamond grains then can be reconstructed.

3. Experimental results and discussion

3.1. Comparison of image segmentation results

In terms of the spatial distribution of gray levels, the micrographs of tool surface as shown in Fig. 1 are rather complex. The upper crystal surface of diamond can reflect light very well, so its



(a) (b) (c) (d)

Fig. 1. Cropped micrographs of diamond protrusion (a) newly protruded diamond; (b) slightly worn diamond; (c) moderately worn diamond; (d) severely worn diamond.