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Mineral image enhancement based on sequential combination of toggle and top-hat based contrast operator

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ABSTRACT

Enhancing mineral image especially making mineral image details clear is very useful for mineral analysis. To effectively enhance mineral image, an algorithm based on the toggle contrast operator and top-hat based contrast operator is proposed in this paper. Sequentially combining the toggle contrast operator and top-hat based contrast operator could be used to identify image features especially the image details. So, appropriately exacting the identified image features by the sequentially combined toggle and top-hat based contrast operator is important for mineral image enhancement, which is analyzed firstly in this paper. After that, the multi-scale extension of feature extraction is given and used to construct the final features for mineral image enhancement. By importing the final extracted image features into the original mineral image through contrast enlargement, the original mineral image is well enhanced and the mineral image details are very clear. Experimental results on different types of mineral images verified the effective performance of the proposed algorithm.

1. Introduction

Microscopy is the important instrument for mineral analysis (Kaiser and Chuvilin, 2003; Shah, 2007; Lumpkin et al., 1997). Obtained mineral images from different types of microscopes, such as scanning electron microscopy, scanning tunneling microscopy and transmission electron microscopy, could provide valuable information for mineral property analysis, new mineral identification, interactions analysis of different minerals and so on (Schultze-Lam et al., 1992; Carter et al., 2000; Jones et al., 2007).

Designing microscopy is an effective way to obtain clear images (Schilders et al., 1998; Reshak, 2009). However, because the operators of microscopy equipment may not well produce the image of mineral samples or the imaging procedure is too difficult to produce clear mineral images, many obtained mineral images do not have good contrast and the contained details are usually not clear. These may affect the applications of these mineral images for the further mineral analysis. Therefore, it is useful to well enhance the mineral images and makes the image details clear.

Image enhancement technique, which is an active research area in image processing, is the effective way for mineral image enhancement (Bai and Zhou, 2011; Heintzmann et al., 2003). Histogram based algorithms (Huang et al., 2006; Wan and Shi, 2007) are widely used and effective ways for image enhancement. But, the bright image regions in mineral image may be over enhanced. Diffusion based algorithms (Tang et al., 2001; Gilboa et al., 2004) are mainly focusing on noise reduction, which is useful for noise smoothing. Filter based algorithm (Foracchia et al., 2005) is also effective for enhancing image regions. But, filters may smooth mineral image details or heavily change the gray distribution. Fuzzy logic based algorithms (Yang et al., 2008; Farbiz et al., 2000) has been used to enhance image, which is also mainly used to remove noises. Utilizing the image information in frequency or wavelet domain performs well for image enhancement in some cases (Agaian et al., 2001; Mencattini et al., 2008). But, the extracted image features in these domains may affect the performance of these algorithms. Morphological operators (Serra, 1982; Soille, 2003), such as top-hat transform (Bai et al., 2012a) and toggle operator (Bai and Zhou, 2011), are also effective tools for image enhancement. Especially, through utilizing the multi-scale theory, image information at different scales could be used for enhancement. Top-hat transform based contrast operator enhances image regions and thus the contrast of an image. But, the image details may not be well enhanced. This will affect the mineral analysis. Toggle operator could be used to enhance details in mineral image, but some details with low contrast may be not well enhanced (Bai and Zhou, 2011; Maragos, 2005; Serra, 1988). To both enhance image contrast and details, sequentially combining the top-hat based contrast operator and toggle contrast operator is an effective way (Bai et al., 2012b) which will produce the resulting image with good contrast and clear image details. This would benefit the further mineral image analysis. Thus, based on the sequential combination of toggle

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contrast operator and top-hat based contrast operator, an effective mineral image enhancement algorithm could be constructed.

In light of this, a mineral image enhancement algorithm through sequentially combining the toggle contrast operator and top-hat based contrast operator is proposed in this paper. Sequential combination of toggle contrast operator and top-hat based contrast operator is discussed, firstly. Then, based on the sequential combination of toggle and top-hat based contrast operator, feature extraction for mineral image enhancement is shown. Moreover, multi-scale extension of the feature extraction is used to extract the multi-scale image features for mineral image enhancement. Through appropriately importing the extracted multi-scale image features into the original mineral image, the mineral image is well enhanced and the image details are clear. The main contributions of this paper are: (1) utilizing the sequentially combined toggle and top-hat based contrast operator for both enhancing mineral image contrast and details; (2) proposing the procedure of feature extraction based on the sequentially combined toggle and top-hat based contrast operator; and (3) extending the feature extraction in multi-scale domain. Experimental results on different mineral images verified the effective performance of the proposed algorithm for mineral image enhancement.

2. Mathematical morphology

Mathematical morphology has been well used in wide area of image processing and pattern recognition (Serra, 1982; Soille, 2003). Dilation and erosion are the two basic morphological operators, which are defined as follows.

$$f \oplus B(x,y) = \max_{u,v}(f(x-u, y-v) + B(u,v)),$$
$$f \ominus B(x,y) = \min_{u,v}(f(x+u, y+v) - B(u,v)).$$

$\oplus$ and $\ominus$ represent the dilation and erosion operators, respectively. f represents the mineral image. B is the structuring element. (x, y) and (u, v) are the pixel coordinates of f and B, respectively.

Based on dilation and erosion, the morphological opening and closing operators are defined as follows.

$$f \circ B = (f \ominus B) \oplus B,$$
$$f \bullet B = (f \oplus B) \ominus B.$$

$\bigcirc$ and $\bullet$ represent the opening and closing operators, respectively. Opening and closing are useful morphological filters for smoothing bright and dark image regions.

Based on opening and closing, the top-hat transforms are defined as follows.

$$WTH_B[f(x,y)] = f(x,y) - (f \circ B)(x,\ y),$$
$$BTH_B[f(x,\ y)] = (f \bullet B)(x,y) - f(x,y).$$

WTH and *BTH* represent the white and black top-hat transforms, respectively. *WTH* and *BTH* could be used to extract bright and dark image regions in an image.

3. Mineral image enhancement

3.1. Morphological contrast operator

3.1.1. Toggle contrast operator

Toggle contrast operator is defined using the primitives and specified rules. Setting dilation and erosion as the primitives, one widely used toggle contrast operator is defined as follows (Serra, 1982; Soille, 2003).

$$TCO_B[f(x,y)] = \begin{cases} f \oplus B(x,y), & \text{if } f \oplus B(x,y) - f(x,y) < f(x,y) - f \ominus B(x,y) \\ f \ominus B(x,y), & \text{if } f \oplus B(x,y) - f(x,y) > f(x,y) - f \ominus B(x,y) \\ f(x,y), & \text{else} \end{cases}.$$

TCO is the selected result from the result of dilation or erosion following the specified rules. Dilation and erosion usually change the marginal regions of image regions. The marginal regions are image details in mineral image. So, *TCO* contains the identified image details by dilation and erosion, which may be well used for enhancing mineral image details.

3.1.2. Top-hat based contrast operator

Top-hat transform extracts bright and dark image regions. By importing the extracted bright and dark image regions into the original image, one top-hat based contrast operator is defined as follows (Serra, 1982; Soille, 2003).

$$THCO_B[f(x,y)] = f(x,y) + WTH_B[f(x,y)] - BTH_B[f(x,y)].$$

THCO contains bright and dark image regions, and enlarges the contrast between the bright and dark image regions. This enhancement identifies the important image regions. These identified image regions are important regions in mineral image, which could be extracted and well used for mineral image enhancement.

The definition of *THCO* indicates that, *THCO* operator is not idempotent. Thus, the gray dynamic of the image may be changed. In another way, it is because of the changing of the gray dynamic of the image, *THCO* could well enhance image regions and the contrast of image. Therefore, *THCO* is a useful tool for enhancing image contrast.

THCO enhances image regions at the scale corresponding to the size of the used structuring element. Although applying *THCO* several times may apparently enhance image regions at one special scale, the image features at other scales will be suppressed. This may result in the ineffective performance. So, applying *THCO* several times is not an appropriate way for image enhancement. Instead, using multi-scale structuring elements in *THCO*, image regions at multi-scales could be enhanced. Then, the contrast of the image which represents the difference between the bright and dark image regions will be effectively enhanced.

3.1.3. Sequential combination of toggle and top-hat based contrast operator

TCO identifies the useful mineral image details, and *THCO* identifies the important mineral image regions. Combining them could both enhance the image details and regions (Bai et al., 2012b) which are important image features in mineral image. These enhanced image features may be extracted for mineral image enhancement. One sequential combination of toggle and top-hat based contrast operator is defined as follows (Bai et al., 2012b).

$$SCO_B[f(x,y)] = TCO_B[THCO_B[f(x,y)]].$$

In this definition, *TCO* and *THCO* are sequentially operated in *SCO*, which would enhance the important mineral image features, including both the mineral image details and regions. The enhanced image features are identified by the *SCO*. This would be useful for mineral image enhancement.

3.2. Feature extraction

The identified image features in *SCO* have different gray values because of the processing by *SCO*. Image details include bright and dark image details. Image regions also include bright and dark