Abrasive Segmentation of Multiple Diamond Images Based on Secondary Morphological Reconstruction

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Abstract. Faced with a lot of noise problems in diamond abrasive image segmentation under complex background, a segmentation method of diamond abrasive images is proposed based on secondary morphological reconstruction. The method of histogram equalization was firstly used to pre-process the original image, which aim is to improve the image by adjusting the global contrast, and an appropriate structural element is constructed to carry out to determine abrasive size by using the morphological smoothing operation; Secondly, the first morphological reconstruction is carried out to further virtualize the complex background and clear target abrasives by using the geodesic corrosion operation; Then, the second morphological reconstruction is carried out by calculating geodesic expansion operation. Combined with the local extreme value processing of the image, each target abrasive area can be obtained. Finally, the segmented target abrasive area is used to extract the multiple abrasives from complex background. It is found that the complex background noise can be readily eliminated by the proposed method, and the abrasives in the image can be well segmented. The results show that segmentation boundary is clear, without background noise, and the segmentation region is significant. The extracted diamond abrasives can be used for advanced image analysis such as abrasive characteristics and abrasive identification.

1. Introduction

Tools with fixed diamond abrasives have been widely used in machining hard and brittle materials, the state of diamond abrasives on tool surface is extremely important due to its effect on tool life and machining efficacy and quality [1]. In order to control the state of diamond abrasives, detecting and analysing diamond abrasives becomes the key issue referring to machining process. In previous studies, manual observation with a microscope was used to detect diamond abrasives, and it has the problems of low efficiency and low accuracy in analysis [2]. In pace with rapid development of information and imaging technology, using image processing technology becomes frequently [3-7]. Compared with natural scene and other public images, practical application images like diamond abrasives are of much different. Diamond abrasive images basically have a lot of noise and tiny textures in the background, such as background with machining textures, reflection noise, acquisition backlight and etc. [8]. Therefore, it is very difficult to segment diamond abrasive image.

Recently, image segmentation methods like using threshold, edge, region, wavelet and other algorithms have been apply to segment diamond abrasive images in order to obtain abrasive features
and optimize diamond tool design. However, existing segmentation methods for diamond abrasive images are hard to segment abrasive gargets from the image with complex noise, results of non-prominent targets, some big noise and indistinct edges are still in the segmented image. Meanwhile, segmentation efficiency is also relatively low. Facing the low segmentation quality of abrasive images with lots of textures and noise in the background, a method of secondary morphology reconstruction is proposed in this paper. Based on the proposed method, the segmentation accuracy and significance can be greatly improved, which is of great help to characterise abrasive states on the tool surface and evaluate abrasive parameters in subsequent advanced analysis.

2. Segmentation method
Figure 1 shows a typical diamond abrasive image, it is seen that diamond abrasives are located in complex background and there are also large morphological differences between diamond abrasives. In order to segment diamond abrasives, the proposed method mainly consists of original image gray scale, histogram processing, morphological reconstruction, morphological operation, target region segmentation, target extraction and etc., the flow chat of abrasive image segmentation and extraction is illustrated in Figure 2. Specific steps of image segmentation and extraction are introduced in this part.

![Figure 1. Typical abrasive image](image1.png)

![Figure 2. Flow chat of abrasive segmentation](image2.png)
2.1. Histogram equalization

For complex background and noise in the image, the most used method of histogram processing is used to obtain an image with uniform distribution of gray level by enhancing the global contrast of the image after image preprocessing process [9]. Assume that an image \( f(x, y) \) has the size of \( M \times N \), its gray level ranges from zero to \( L-1 \). When the gray level value is \( r_k \), the probability of \( r_k \) in image can be defined as

\[
p_{r}(r_k) = \frac{n_k}{MN}
\]

where \( MN \) is the total pixels in image, \( n_k \) is the pixel number of \( r_k \), subscript \( k \) ranges from zero to \( L-1 \), and \( L \) is the maximum gray level in the image.

Based on the probability \( p_k \), its cumulative function is described as

\[
CF(r_k) = \int_{0}^{r_k} p_r(r) \, dr
\]

Hence, the adjusted image with the new gray level of \( s_k \) is obtained as

\[
s_k = \frac{CF(r_k) - CF_{min}}{MN - CF_{min}} \sum_{j=0}^{k} n_j
\]

where \( CF_{min} \) is the minimum value of \( CF(r_k) \), and subscript \( k \) ranges from zero to \( L-1 \).

2.2. Abrasive size determination

After histogram processing, a gray image \( G \) can be obtained, but there is still some complex noise. In order to blur the background noise and retain the characteristics of diamond abrasives, detecting the distribution of abrasive size is very important. Hence, a method of detecting abrasive size is used in the present paper, and a specific structural element is used for image morphological smoothing. Basically, morphology operators includes expansion operator and corrosion operator. When using morphology, we need to define a structural element \( S \), and input \( S \) into the image \( G \) by translating continuously. When it is translated to \( (x, y) \), the structural element becomes \( S_{xy} \).

When \( S_{xy} \cap G \) is not an empty set, it is defined that \( S \) expands \( G \).

\[
G \oplus S = \{ x, y \mid S_{xy} \cap G \neq \emptyset \}
\]

Where \( \oplus \) represents expansion operator.

When \( S_{xy} \subseteq G \), it is defined that \( S \) corrodes \( G \).

\[
G \ominus S = \{ x, y \mid S_{xy} \subseteq G \}
\]

Where \( \ominus \) represents corrosion operator.

Based on open operation (\( \oplus \)) and close operation (\( \ominus \)) of the morphology, results of dilation and erosion are given as follows, respectively

\[
G \bullet S = (G \oplus S) \ominus S
\]

\[
G \circ S = (G \ominus S) \oplus S
\]

2.3. First morphological reconstruction

Based on the abrasive size determination, the new gray image \( f \) after background virtualization can be obtained. The irregular background can be further removed by using the method of gray morphological reconstruction. We define that the marker image and the template image are represented with \( G \) and \( f \).
respectively. It should be mentioned that the size of two kind gray images has the same size. Thus, the definition of morphological reconstruction is given as

$$E_G^{(n)}(f) = (f \Theta S) \lor G$$  \hspace{1cm} (8)

Where $S$ is the structural element, $\lor$ is the point mode maximum operator.

Then, calculating $S$ to corrode $f$, obtaining the value of each point $(x, y)$, and comparing with $G$ to get the maximum one.

$$E_G^{(n)}(f) = E_G^{(n-1)}[E_G^{(n-2)}(f)]$$  \hspace{1cm} (9)

Where $E_G^{(0)}(f) = f$

The first morphological reconstruction is completed when the image is relatively stable through repeated iterations of $G$ to $f$ geodesic corrosion. Thus, the results can be described as

$$R_G^{(0)}(f) = E_G^{(0)}(f)$$ \hspace{1cm} (10)

After the first morphological reconstruction, the obtained image is recorded as $F_1$, which can largely removal the influence of complex background noise, estimate the size distribution of abrasives, and retain the basic contour of abrasives.

2.4. Second morphological reconstruction

Based on the obtained image of $F_1$, it needs to be further morphologically reconstructed by using geodesic expansion in order to clear abrasive boundaries and further remove the background noise. The image $F_2$ obtained by second morphological reconstruction can be defined as follows

$$D_G^{(1)}(F_1) = (F_1 \oplus S) \land G$$ \hspace{1cm} (11)

Where $S$ is the structural element, $\land$ is the point mode minimum operator.

Then, calculating $S$ to corrode $F_1$, obtaining the value of each point $(x, y)$, and comparing with $F_1$ to get the minimum one.

$$D_G^{(n)}(F_1) = D_G^{(1)}[D_G^{(n-1)}(G)]$$ \hspace{1cm} (12)

Where $D_G^{(0)}(F_1) = F_1$

The second morphological reconstruction is completed when the image is relatively stable through repeated iterations of $F_1$ to $G$ geodesic expansion. Thus, the results can be described as

$$R_G^0(f) = D_G^0(F_1)$$ \hspace{1cm} (13)

After the second morphological reconstruction, the obtained image basically has little background noise, and the image has clear abrasive contours.

2.5. Local extremum

The abrasive image obtained by the second morphological reconstruction basically eliminates the background noise, but the abrasive target is also fuzzy to a certain extent at the same time. So, it is necessary to locate the target. Here, the local extreme value processing method is used to find the extreme value to determine the location of the abrasive target. When the connected components is larger than a certain threshold value, the area is set as white, and the rest are black. Thus, the position of the abrasive target can be readily obtained.

2.6. Abrasive segmentation

After local extremum processing, an image of $H$ is obtained. Through multiplying it with the image $f$, interest objects are segmented from the original image. The segmented image $T$ can be expressed as

$$T = fH$$ \hspace{1cm} (14)
3. Image acquisition and Experiment
Diamond abrasive images were acquired by a Hirox KH-1000 video microscopy system, which minimum and maximum magnification is 50× and 1000×, respectively. Diamond abrasive size is about 40 μm. All the acquired images, saved in JPEG format, have 640 pixels (width) and 480 pixels (height).

Image processing experiments is written in C++ language, and it runs on a Dell workstation under Windows seven operating system (Sixty-four Bits). The Dell workstation has an i7 processor (highest frequency 2.4 GHz) and DRR3 memory (8 GB of RAM).

4. Results and discussion
In order to compare the segmentation effect, original abrasive image was firstly adjusted by using histogram equalization. After that, classical Canny, Sobel, Otsu and iterative threshold algorithms were used to segment the image. Then, proposed method in this paper was also used to segment the abrasive image. Both of the segmentation results are shown in Figures 3 and 4, respectively.

Based on Figure 3(a), it is observed that the colour distribution of some abrasive targets is very similar to the background, and transition between the target and the background is relatively smooth. Moreover, the background has many textures. After histogram equalization, the image has significantly contrast effect, and the abrasive target are clearer, as shown in Figure 3(b). When the abrasive image is segmented by the Canny algorithm, the results show that there are very rich edge features in the background in Figure 3(c). As the detected abrasive edge falls into the background texture edges, the abrasive segmentation effect is very poor, and segmentation significance is very low, which indicates that it is difficult to analyse the interested abrasives in the subsequent analysis. When the abrasive image is segmented by the Sobel algorithm, similar results were obtained shown in Figure 3(d). When using Ostu segmentation algorithm to segment the image, as shown in Figure 3(e), the similar gray-level parts of abrasive targets and background textures are segmented. Although the abrasive targets have a good segmentation results, its background still has lots of noise features, which leads to a little low segmented significance. In Figure 3(f), the image was segmented by the iterative threshold segmentation algorithm, the results are still similar to Ostu’s.

Figure 3. Abrasive segmentation results based on classical algorithms. (a) Original abrasive image, (b) Histogram equalization, (c) Canny, (d) Sobel, (e) Ostu and (f) Iterative threshold.

Based on the above analysis, it can be found that classical algorithms obviously have over segmentation, which often occurs in the regions that the target and the background have similar gray level distribution. Thus, the adaptability of such abrasive image segmentation is poor, and the results still have many features of non-interest textures and noise in the background.

Figure 4. Abrasive segmentation results based on proposed algorithm. (a) Original abrasive image, (b) Abrasive size determination, (c) First morphological reconstruction, (d) Second morphological reconstruction, (e) Local extremum and (f) Abrasive segmentation.
Figure 4 shows the segmentation results based on the proposed method, it can be found that the background noise is greatly weakened and the target abrasives are well measured after using abrasive size determination, as shown in Figure 4(b). For abrasive edges are virtualized during abrasive size determination, the abrasive regions are expanded. When using the first morphological corrosion reconstruction, the results show that the significance of the target abrasive and the background is greatly improved shown in Figure 4(c), especially at the area that the abrasives and the background have near gray level components. However, there are still some background noise and some abrasive edge is lost. When using secondary morphological reconstruction, it can be found that the problems occurred in in Figure 4(c) can be readily solved. The abrasives can be basically segmented from the background as shown in Figure 4(d). However, the overall image contrast is weak, and there are holes in the abrasive particles. In order to solve the above problems, the method of local extreme value processing was adopted in abrasive segmentation, the results are shown in Figure 4(e). It can be seen that the complete abrasive targets are basically segmented. Based on the segmented abrasive regions, all target abrasives in the image are finally completely segmented from the original image, as shown in Figure 4(f). Based on the segmented results, it can be found that the background noise is eliminated, and the segmented abrasives basically have clear edges, which validates that the proposed method has great significant segmentation effect.

Compared with the results of abrasive image segmentation in previous studies [3, 5], there is no background noise in the segmentation results of the abrasive image in this paper. The results indicates that the proposed method can segment the abrasive targets directly from the abrasive image, which can be used to characterise the abrasive states and parameters, such as abrasive number detection, abrasive shape analysis, abrasive size measurement and etc., in subsequent abrasive analysis.

5. Conclusions
Complex background textures and noise is responsible for the difficulty of abrasive segmentation for multiple diamond images. In order to segment diamond abrasives with high saliency from the acquired images, an abrasive segmentation method of secondary morphological reconstruction is proposed in the present paper. According to the experimental results, main conclusions can be obtained as

- The classical algorithm is not competent for the segmentation task of diamond abrasive images due to the binding agent, complex textures and noise in the background.
- Segmentation results based on classical algorithms show that the significance of the target area is low, and a lot of background noise still remained.
- The proposed method based on secondary morphological reconstruction can better complete the task of abrasive image segmentation. The results show high saliency and little noise.
- The segmented results based on the proposed method can be used to characterise the abrasive states and parameters, such as number determination and abrasive evaluation.

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