Materials Science Forum Vol. 770 (2014) pp 427-432
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doi:10.4028/www.scientific.net/MSF.770.427

The Segmentation of Ferrography Images: A Brief Survey

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Keywords: Wear, Image segmentation, Ferrography, Ferrography image

Abstract: This paper provides a general overview on the developments and progress in the segmentation of ferrography images. The problems experienced with applying traditional image processing methods in the segmentation of wear particles, revealed that it is still a big challenge for intelligent ferrography. This has highlighted the need for combining the segmentation and clustering methods for performing ferrography image analysis. In this paper, some of the developments reported in the literature relating to progress made with wear particle image segmentation are reported and examined as a basis for establishing improved methods of ferrography image analysis.

Introduction

For the modern, large-scale and continuous production equipments, monitoring its working condition, and implementing the condition-based maintenance system are the key issues to ensure high production efficiency.

More than 80% of the equipment failure is due to the wear on components. Ferrography was developed in 1970s as a wear condition monitoring and fault diagnosis technology. It determines the wear condition and failure mechanisms of the equipments through quantitative and qualitative analysis on the quantity, size, shape, and color of wear particles in its lubrication system. The increasing of wear particle concentration shows that wear rate increases in the system, the large size of the wear particles appear in large numbers indicate the occurrence of severe abnormal wear [1].

Ferrography is considered to be the most effective condition monitoring and fault diagnosis technology for low speed and heavy duty machinery [2] in the petrochemical and mining industry. Because an advantage of ferrography is that it is effective to examine the abnormal large particles, the combination of ferrography and atomic emission spectroscopy are considered as irreplaceable technical means to ensure the safe operation of aircraft engines and transmissions [3,4].

Much effort has been dedicated to developing a computer-aided image analysis system to improve the accuracy and efficiency of wear particle identification processes. However, most progress are made in the application of image processing techniques for feature extraction and wear particle recognition[5-10], as for the ferrography image segmentation, it is still a challenge to achieve accurate segmentation of wear particle deposited chains, then to obtain the quantitative characteristics of a large number wear particles. This paper will summarize the research in the segmentation of ferrogrphy images.

Difficulties in ferrography image processing

Although in recent years, the research of wear particle segmentation and identification technology have made many achievements, the applications of ferrography analysis system in industrial field have also made great progress, but because characteristics of wear particles has complexity, randomness and ambiguity, it still has a big gap between the system's automation and application, there are still some problems as following:

1) Gradient magnetic field is used to separate ferrous particles from the lubricant which results in the ferrous particles deposited in form of chains along with the magnetic force direction. Particles connect, some of them even overlapping with each other. The deposited chain may be composed of a number of fine abrasive particles, or may also contain some abnormal large wear particles, as shown in Fig.1 and Fig.2.

2) Different types of wear particles have different characteristics, such as shape, profile, size, color and texture information.

3) Due to the different color or reflective properties of particles, the color and brightness of image background also uneven.

4) For the thick wear particles, they would have vague edge and profile because the focal depth of the microscope is small.

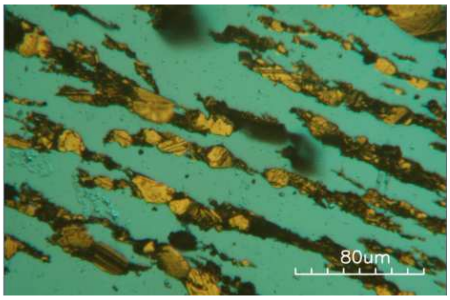

Fig.1 Wear particle deposited chains

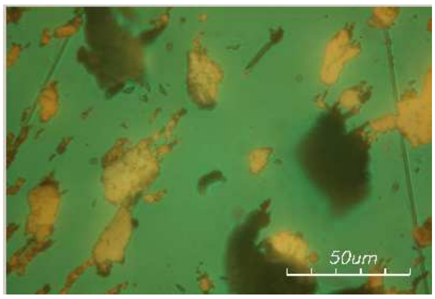

Fig.2 Abnormal large wear particles

Therefore, how to effectively segment the wear particles, particularly, the abnormal large particles within deposited chain to facilitate the further identification, it is the key issue of the current ferrography image analysis.

The development of ferrography image segmentation

Ferrography image segmentation is the first step in ferrography analysis and pattern recognition. It is a critical and essential component of ferrography analysis system, is one of the most difficult tasks in image processing, and determines the quality of the final result of analysis. Image segmentation is a process of dividing an image into different regions such that each region is homogeneous.

The segmentation of ferrography images based on binarization. Image binarization based on gray threshold is a commonly used method in the early ferrography image processing

In 1994, Roylance et al. developed a new interactive control system, CAVE (Computer-aided vision engineering). It can perform some image processing procedures, such as binarization, noise reduction, edge tracking etc. Quantitative methods for determining the morphological attributes of particles have been established in terms of their size, shape, and profile by the interaction with the operator[11].

Zhan et al. discussed some preprocessing technique for ferrography images such as smoothing, filtering, and threshold method, and then, a new method - debris selection is developed, which is based on the iterative convolution in the whole map with a blank, size variable window. It is applied to the processing of a real ferrography image, it can be used to reduce noise and simplify data processing [12].

Hu et al. uses two methods of image enhancement - weighted mean filtering and adaptive median filtering to improve the image quality to facilitate the following target segmentation and extraction [13].

Otsu thresholding algorithm is the most often used binarization method in ferrography images processing. Fig.3 and Fig.4 are two examples of Otsu thresholding algorithm applying to ferrography images. It can be found that the separation of wear particles with image background could be obtained. However, if the background of ferrography is uneven, as shown in Fig.3, part of the background may be mistakenly divided as wear particles. And for wear particles which are too bright, as shown in Fig.4, the particles may be mistaken into background. In this approach, since the threshold value is obtained from the histogram only which lead to the difficulties of accurate result.

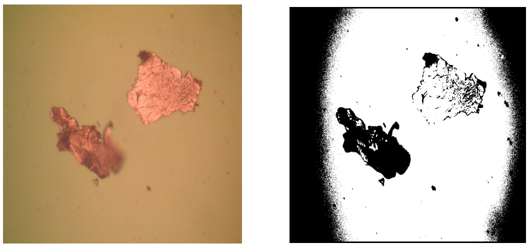

Fig.3 Original image and Otsu segmentation

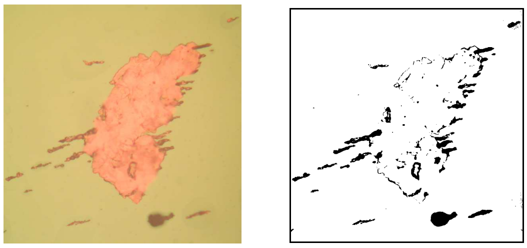

Fig.4 Original image and Otsu segmentation

The segmentation of image background and wear particles. Ferrography images are obtained by using an optical microscope with transmitted and reflected light illumination. Different combination of transmitted and reflected light will result in different background colors in the image. For example, under the white reflected light and green transmitted light illumination, the background color is green in ferrography images, while, under the red reflected light and green transmitted light, background color is dark yellow.

In addition, the point source of light of microscope will lead to inconsistent background more or less in images; wear particles also have a great range of variation in color and brightness, wear particles with brightness above or below the background may occur simultaneously in ferrography images. As the small depth of focus of an optical microscope, the thick wear particles have blurred outlines at high magnification; the reflective of wear particles can also cause uneven background. These problems are inevitable difficulties in segmentation of wear particles and background.

Gao et al. pointed out, it is difficult to separate wear particles and background based on the traditional gray histogram threshold method, because no matter where the threshold is set, some too bright or too dark wear particles could not be divided from image background, resulting in incomplete segmentation[14]. Therefore, some complex algorithms, such as adaptive fuzzy threshold segmentation[15], two-dimensional maximum entropy genetic algorithm [16] are needed in the segmentation of ferrography images.

To address this issue, Chen et al. proposed that the RGB or HSV color space should be used in the segmentation of wear particles with image background, and fuzzy clustering techniques should also be used for the segmentation of background and wear particles [17].

Many researchers proved that more accurate segmentation results could be obtained by using threshold method in color space than in the gray space [18-20]. Color information can be used to determine the wear modes and the ingredients of wear particles, along with in-depth applications of image processing technique in wear particle analysis, researchers began to study color image processing methods for segmentation and feature extraction of wear particles [21, 22].

Xin et al. proposed a segmentation method of color ferrography image based on multi-threshold wavelet transform. By this method, the color ferrography image was segmented into three-level images, the histogram graphs of the monochrome images were segmented to form three separate regions, that is the background color, the general wear particles and abnormal wear particles based on multi-threshold wavelet transform as shown in Fig.5 [23].

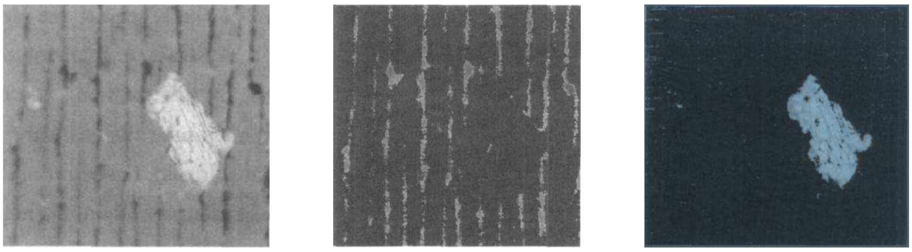

Fig. 5 Original image, dark wear particles and bright wear particle

Wang et al. compared segmentation and clustering effect for ferrography images in different color space, and then proposed the 2D k-means color clustering algorithm in CIELAB color space [24, 25]. In the CIELAB space, *L* represents lightness, *a* and *b* are two different color components. By using k-means clustering based on two color component (*a*, *b*), ignoring the affect of luminance component *L* on the image, a better segmentation result could be obtained. It can be seen from Fig. 6, the debris particles including dark and bright ones could be separated directly from the background of images.

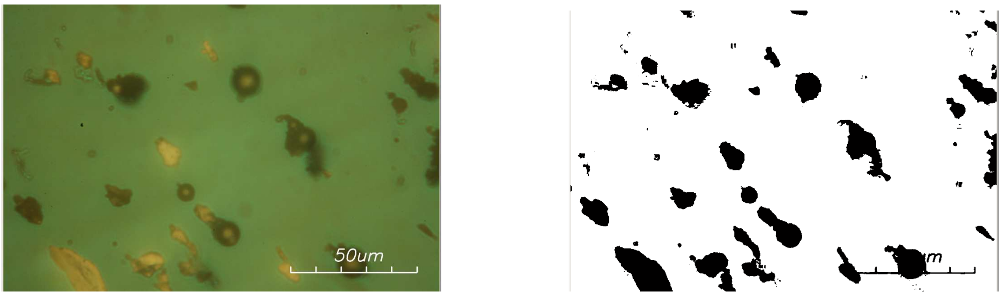

Fig. 6 Original image and segmentation result of 2D k-means color clustering in CIELAB color space

However, 2D k-means color clustering algorithm cannot segment wear particles by itself. It can only subtract the background from images for the further processing, or it can be combined with other approaches, e.g., region based segmentation approaches, to complete the segmentation tasks of wear particles.

The segmentation of wear particles. The segmentation of wear particles is the pre-treatment for feature extraction and recognition in ferrography images. Because the concentration of wear particles and the magnetic field during the deposition process, wear particles on ferrogram always adjacent to each other, more evenly, some particles may overlapping. In addition, the random and complex morphology (shape, color, surface) of an individual wear particle also result in the problem of difficult segmentation. Some researchers have indicated the segmentation of wear particles is even more difficult than recognition[26]

Li et al. introduced mathematical morphology to ferrography image segmentation [27]. By using erosion and dilation operation on binary images, the edge of single wear particle was successfully detected with Laplace operation, as shown in Fig.7.

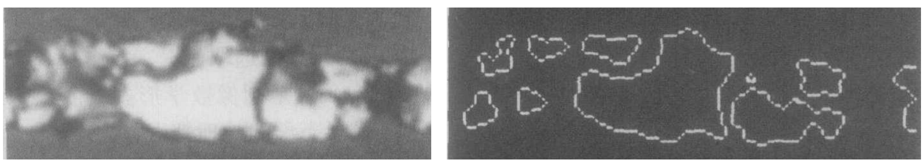

Fig.7 Typical wear particle chain and the result of edge detection

Hu et al. applied some pretreatment techniques included image enhancement, image segmentation, filling pore and image erosion to ferrography images. Subsequently, high-brightness wear particles are extracted from deposited chains by using the adaptive threshold method [28]

Wang et al. proposed the combination method of 2D k-means and watershed for the segmentation of wear particles [25]. At first, the k-means clustering is used to divide image background and wear particles. Then the k-means clustering results is considered as basic image for watershed segmentation, particle and background marker image can be extracted from it by using mathematical morphology methods. Next, the watershed algorithm is adopted to achieve automatic segmentation of particle deposited chains, as shown in Fig.8. By means of the integration of these two algorithms(k-means clustering & watershed segmentation), considering the k-means clustering results as basic image for marker image of watershed segmentation, both the pixel color (pixel value for clustering) and the pixel space information (connected region for watershed segmentation) have been used during the image processing, which result in better segmentation.

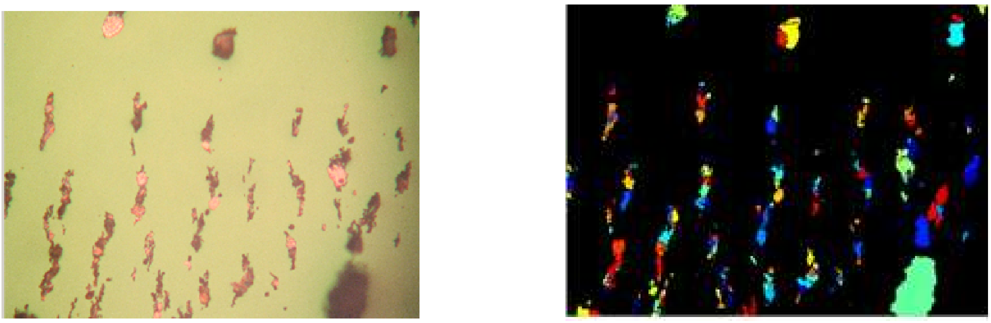

Fig.8 Original image and watershed segmentation result

However, due to the noise and uneven distributed gray level on particle surfaces, over-segmentation may happen in some cases, especially on the surfaces of large wear particles, as shown in the ellipse in Fig. 9. To solve the over-segmentation of large wear particles, the intelligent clustering algorithm should be studied in future.

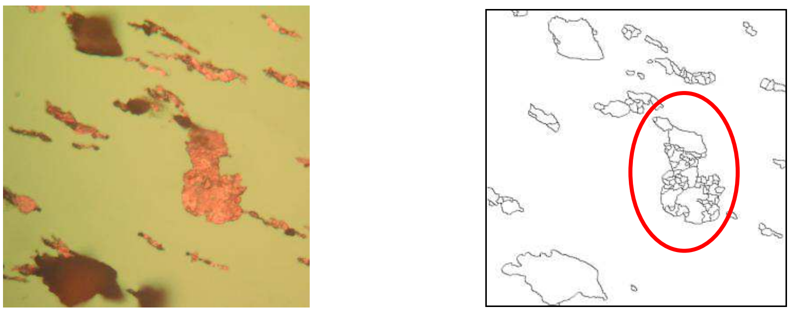

Fig.9 Original image and over-segmentation of large wear particle

Summary

Ferrography image segmentation is the first step in ferrography analysis and pattern recognition. It is a critical and essential component of ferrography analysis system, is one of the most difficult tasks in image processing, and determines the quality of the final result of analysis. Based on the above analysis, future studies should dedicate to improve the intelligence and automation level of ferrography image processing and analysis. By selecting suitable color space for image processing, optimizing the color components, seeking parallel intelligent image segmentation and clustering algorithms to achieve the fast and accurate segmentation between wear particle and background, or wear particles.

Acknowledgements

This research is supported by the National Natural Science Foundation of China (No. 51205202) and A Project Funded by Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

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