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Restoration of low-informative image for robust debris shape measurement in on-line wear debris monitoring

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ABSTRACT

As a significant technique in machine condition monitoring, wear debris analysis enables investigation of machine running condition with respect to debris features including size, quantity and morphology. In particular, being capable of providing more comprehensive morphological information, three-dimensional debris features are regarded essential and often acquired through a video-based debris imaging process. However, debris images captured often suffer degradation due to debris motion blur and lubrication contamination, that hinder reliable debris features extraction. To address the image degradation issue, a new method of wear debris image restoration is developed to reduce the effect of blur. In order to avoid the expensive computation involved in blind deconvolution methods, the debris image was restored using localized boundary features. Based on the fact that debris area and background area indicate distinctive brightness, a step edge model is applied to describe the original debris boundary. Localized kernels on each side of debris are then determined. Next, restorations are conducted with the estimated kernels to produce sharper debris profiles with respect to different motion features. Final restoration is conducted by fusing the restored profiles according to the maximum local sharpness. Experimental results have demonstrated that this method allows reliable features extraction from blurred image, improving the robustness of video based wear debris analysis.

1. Introduction

Condition monitoring of machinery is widely used to evaluate machine operation status so that proper maintenance can be scheduled to postpone or avoid catastrophic failure. Among the existing condition monitoring strategies, wear debris analysis has been recognized as a highly effective one [1]. By inspecting debris characteristics including quantity, size and morphology, wear status of mechanical components can be estimated [2–5]. To obtain comprehensive debris features, in particular, for wear mechanism assessment, image-oriented debris monitoring such as ferrography was developed [6]. However, those traditional approaches are being challenged recently, due to demands for rapid data interpretation in modern condition monitoring [7]. Consequently, sensing approaches had been redirected towards on-line wear debris image acquisition and analysis.

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Over the past decades, various image based on-line wear debris analysis methods have been developed to conduct real-time debris data acquisition and interpretation [8]. Implementation of those sensing techniques proved that on-line approaches provide data more efficiently, and making it possible to schedule more timely maintenance. However, compared with tradition ferrograph images from which elaborated debris features can be extracted, current on-line wear debris images only allow to extract features such as quantity, concentration, size and color, which are mainly about statistical characteristics. The detailed morphology information of individual debris that are significant in wear mechanism interpretation, however cannot be reliably extracted so far. This is mainly because the limited image quality which has made the extraction of reliable debris morphology an intractable issue.

In addition, by examining the information on height direction, 3-D debris features have been proved effective in the identification of fatigue chunk, laminar and sliding debris [9]. However, those comprehensive features are not accessible by most existing on-line debris images. A video based debris sensing strategy then was developed for observing wear debris features in multiple views [10]. Experimental result has demonstrated that this method outperforms current 2-D methods by providing volume and height information of wear debris [11]. Nonetheless, the captured debris images often suffer from motion blur due to debris motion when its images are captured. The extracted debris morphology is accordingly significantly affected by the blurry effect.

As can be concluded, the fundamental shortage of current on-line debris image lies in the fact that the image quality is often limited due to contamination and motion blur. Correspondingly, restoration is needed to improve the quality of debris images, allowing the on-line wear debris image to provide more detailed debris features. Image restoration is not a new topic and numerous techniques including inverse filtering, Wiener filtering, least-square filtering and constrained iterative deconvolution methods have been developed [12–16]. However, these techniques cannot be directly applied to address on-line wear debris image as little blur features are known due to the random debris motion. Correspondingly, another estimation strategy called blind deconvolution were proposed to obtain the sharp image and blur features simultaneously [17]. Successful as the restoration is, the iterative computation is relative expensive for on-line wear debris image improvement.

Compared with general blurry image, wear debris image indicates some unique features. First, the blurry effects are mainly generated due to debris motion during the exposure. Furthermore, the information carried is relative lower because of oil contamination and low resolution. Due to this concern, previous research had been carried out to restore the motion-blurred debris image by identifying zeros from the cepstrum of each frame [10]. However, it only works in the scenario with high signal to noise ratio. In on-line monitoring, as the video quality is limited due to the commonly occurred lubrication contamination and resulting in low information content videos, it is difficult or even impossible to identify those periodic zeros. Therefore, a deblurring strategy which allows restoration of debris image with low information content is developed in current work.

The rest of the paper is organized as follows. Related background including wear debris imaging equipment and blurring phenomena of on-line wear debris image are given in Section 2. Section 3 presents the developed method which is composed of four main steps: (1) edge prediction, (2) kernel estimation, (3) primary restoration and (4) image fusion. In Section 4, a 3-D reconstruction experiment is conducted based on real debris profiles to evaluate the performance of the developed method. Finally, a conclusion is given in Section 6.

2. Wear debris sensing equipment and image degradation

In traditional off-line ferrography image analysis, debris are usually manually cleaned and placed on a slide, imaged by a microscope for further examination. However, only single-sided information can be obtained by those approaches. For the purpose of rapidly collecting more comprehensive morphology information, a video based debris imaging system is used [18].

2.1. Video based wear debris analysis

The video based imaging system allows to observe wear debris in different directions by collecting the projected profiles of wear debris from multiple views in images. The system diagram is shown in Fig. 1a.

Lubrication oil containing wear debris is pumped to a micro fluid channel, where a camera is mounted. Due to the viscous drag applied, debris in the fluid channel will rotate and its profiles in multiple views are captured, see in Fig. 1b. Based on those collected profile sequences, three dimensional shape of wear debris can be reconstructed and more detail debris features including volume and thickness can be extracted for wear mechanism interpretation [11].

2.2. Degradation of wear debris image

Video based imaging is capable of acquiring debris information in different views and previous work has been conducted to make it practical in machine monitoring. For instance, debris occlusion can be found when the concentration of debris is large. Debris separation was investigated to extract individual debris from cluster [19,20]. In addition, debris occlusions can also be addressed via a tracking process which allows to identify debris profiles in different poses [21]. However, the performance of current video based debris imaging still needs to be improved as current debris image suffers degradation. It