Mechanical Systems and Signal Processing 93 (2017) 80–91

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

The monitoring of micro milling tool wear conditions by wear area estimation

Kunpeng Zhu [a,*], Xiaolong Yu [a,b]

[a] Institute of Advanced Manufacturing Technology, Hefei Institutes of Physical Science, Chinese Academy of Sciences, Huihong Building, Changwu Middle Road 801, Changzhou 213164, Jiangsu, China
[b] Department of Automation, University of Science and Technology of China, Hefei 230026, China

ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 16 January 2017
Accepted 4 February 2017

Keywords:
Micro milling
Tool wear area estimation
Morphological component analysis
Region growing

ABSTRACT

In micro milling, the tool wear condition is key to the geometrical and surface integrity of the product. This study proposes a novel tool wear surface area monitoring approach based on the full tool wear image, which can reflect the tool conditions better than the traditional tool wear width criteria. To meet the challenges of heavy noise, blur boundary, and mis-alignment of the captured tool wear images, this paper develops a region growing algorithm based on morphological component analysis (MCA) to solve the problems. It decomposes the original micro milling tool image into target tool images, background image and noise image. Then, the region growing algorithm is used to detect the defect and extract the wear region of the target tool image. In addition, rotation invariant features are extracted from wear region to overcome the inconsistency of wear image orientation. The experiment results show that region growing based on MCA algorithm can extract the wear region of the target tool image effectively and the extracted wear region also has good indication of tool wear conditions. It also demonstrates that the estimation of wear area can generalize the tool wear width estimation approach, and yield more accurate results than the traditional approaches.

1. Introduction

Micro-milling has wide applications in micro and ultra precision devices for its prominent capabilities in versatile material processing and complex 3D surface machining. However, due to the nature of ultra-high speed interrupted cutting and micro-scale tool, the tool wear appears quickly. The tool wear condition has direct effects on the quality of products. Serious tool wear can also cause tool breakage, break off and chatter, which would even harm to the machine tool. An effective the tool wear monitoring is most important [1]. Previous work mainly includes two categories: one of them used indirect method such as cutting force, vibration and acoustic emission to infer the tool wear condition; another one employed direct method such as digital image processing techniques in milling tool image to monitor the tool wear condition.

The indirect methods mainly apply sensor signals, including force, vibration, and acoustic emission (AE) to estimate tool wear conditions. Tansel et al. [2] studied the fracture and wear of vertical milling cutter groove on mild steel and aluminum, they estimated the wear of the cutting tool by monitoring the feed direction of cutting force on workpiece. They also controlled the cutting force by dynamically adjusting the cutting parameter to extend the service life of cutting tools. By

* Corresponding author.
E-mail address: kunpengz@hotmail.com (K. Zhu).

http://dx.doi.org/10.1016/j.ymssp.2017.02.004
0888-3270/

analyzing the time-frequency characteristics of cutting force and dynamic characteristic, Zhu et al. [3,4] proposed methods based on stochastic process modeling of cutting forces and tool conditions; it achieved good tool wear monitoring results by considering denoising and discriminant force feature extractions. Others tried vibration analysis. Lamraoui et al. [5] investigated tool wear monitoring using the vibrations from high speed milling, and showed that the tool wear and the number of broken teeth on the excitation of structure resonances appeared in its Wigner-Ville representation. Hsieh et al. [6] also detected the variation of tool wear through vibration analysis, and found the vibration was sensitive to the directions and the feature selection was important with neural network classification. Another popular tool wear monitoring approach is by acoustic emission. It has advantage in that the signal measured is a source of engagement where the chip is formed. Prakash and Kanthababu [7] and Hung and Lu [8] utilized acoustic emission signal in the micro milling tool wear monitoring field respectively. They claimed that there were strong relationships between the tool wear (flank wear) and acoustic emission signals. The acoustic emission signal and its frequency spectrum characteristics could monitor the tool wear monitoring and meet different application aspects. Yen et al. [9] applied AE signals together with intelligent approaches and achieved satisfactory tool wear classification results. By fusion different sensors, Duro et al. [10] proposed a multi-sensor data fusion system to enable identification of the best sensor locations for monitoring cutting operations, and it was found this framework could improve signal interpretation and enhance the monitoring system reliability. Malekian et al. [11] developed a comprehensive system and fused various signal features for the tool wear monitoring in micro milling. The indirect methods generally has drawbacks with small amplitude (force, vibration), low signal-noise rate (force, vibration), wide band and high sampling frequency (AE) in the micro milling monitoring. It has always been a difficult task to establish a reliable relationships between the signal features and tool wear states under varying working conditions.

In order to overcome the shortcomings of the indirect methods in cutting tool monitoring, researchers proposed direct monitoring methods based on tool wear image captured. Due to the development of high speed cameras, this approach has benefits of high precision, large dynamic ranges and indirect contact, and it attracts more attention in the research. Kurada and Bradley [12] implemented a direct tool condition monitoring system using two fiber optic lighting and CCD cameras to obtain the tool flank wear images. They put to use a cascade median filter to reduce the image noise and utilized image segmentation method to extract tool wear area from its background. The error rate was not satisfactory as reported however.

On the basis of the combination of tool wear measurement and classification, Lanzetta [13] put forward a kind of automatic load sensing system, and the resolution of the sensor reached 0.04 mm/pixel. Zhang et al. [14] developed a technique for the tool wear measurement based on machine vision to extract the edges of the tool wear region by column scanning. To achieve a more accurate result, they adopted the sub-pixel edge detection technology to extract the edges. Su et al. [15] studied the feasibility of the digital image processing method, which was used to measure the micro-drilling tool (the diameter is 0.2 mm) of flank wear. Other researches also tried image analysis approaches such as image reconstruction [16], boundary detection [17], texture analysis [18,19], and successive image analysis [20]. Kuttolamadom et al. established a volumetric tool wear measurement method [21] and found that the volumetric tool wear rate was it is closely related to the material removal rate when milling Ti–6Al–4V [22]. This study devoted to the understanding of the wear evolving in 3D. This system is rather computationally and physically expensive with 3D surface profiler scanning, and hard to be implemented online/in-process however. A more convenient way of 3-D measurement was proposed with a phase-shifting method by Wang et al. [23]. Lachance et al. [24] did a pioneering work to extract and segment the wear surface from grinding wheel image background their method had solved the precise selection problem of intensity threshold and boundary threshold. However, their algorithm was did not take account the image morphology, which was inherent in tool wear image and important in determination of tool wear area.

It is noted that the current literatures mainly measured the tool wear width and regarded it as the tool wear criteria, and the wear land area has been little investigated in micro-milling to our best knowledge. However, in the micro milling, the cutting edge has different working load along the edge, and the wear rate varies in different area as a result. At the same time, the tool wear area is strongly irregular because it is produced in complex mechanical and thermal environment. So, a more comprehensive geometric properties such as the wear area was needed to serve as an important basis of judging the degrees of tool wear. To meet this challenges, this paper proposes a novel region growing algorithm based on MCA to extract micro milling tool wear region and estimate its wear area. It could precisely estimate the tool wear area and handle the tool wear image that has heavy noise, blur boundary, and uneven grey value distributions. Details of the approach is developed in the following section.

2. The detection and estimation method of the wear land area of micro milling tool images

Region growing is a kind of image segmentation algorithm and has been widely used in image processing field. It can segment the connected areas which have same characteristics, as well as provide good boundary information and segmentation results. In the absence of prior knowledge, the region growing method can get the good performance [25]. However, the traditional region growing method is not robust when it partitions micro milling tool wear images. If the tool background image greyscale is uneven in the target region, it will lead to early termination of the regional growth. On the contrary, if the boundary of the image background and the cutting tool are blur, it will give rise to overgrowth of region growing. How to eliminate the background on the tool wear region is key to the successful defect detection using the region growing algorithm. For the latest years, the morphological component analysis [26], which synergies with the sparse representation methods [27], has