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Texture analysis methods for tool condition monitoring

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Abstract

Tool wear dramatically affects the texture of the machined surface. Analyzing the texture of machined surfaces has been shown to be promising for tool wear monitoring. However, most methods have their limitations when applied to real environments, where the geometric features of machined surface depend on the machining operation, and where image quality is affected by illumination and other factors. Problems of non-uniform illumination and image noise can be reduced by applying image segmentation and image enhancement techniques. This paper discusses our work on statistical and structural approaches for analyzing machined surfaces and investigates the correlation between tool wear and quantities characterizing machined surfaces. The column projection method can be used for machined surfaces with highly repetitive and regular textures while the connectivity oriented fast Hough transform based method is able to characterize surfaces produced by various machining processes and conditions. Our results clearly indicate that tool condition monitoring which is defined as the ability to distinguish between a sharp, a semi-dull, or a dull tool can be successfully accomplished by analysis of statistical and structural information extracted from the machined surface.

Keywords: Machine vision; Texture analysis; Tool wear monitoring

1. Introduction

Tool wear monitoring is a critical operation in automatic manufacturing. It is directly related to the production efficiency and the quality of machined objects. The shape of a cutting tool used in a machining operation changes due to different types of wear. A cutting tool experiences a very complex pattern of wear as it cuts the material and certain parts of the cutting tool loose material due to wear mechanisms including abrasion, adhesion, and attrition. Furthermore, there is a chipping of the cutting edge due to low cyclic fatigue and the brittle failure of tool material. The tool wears on all sides more or less simultaneously, however wear on one or more sides of the cutting edge may dominate. The wear on the clearance face known as flank wear and wear on the rake face known as crater wear have been commonly measured using cameras, whereas the measurement of nose wear and breakage of the cutting edge is not that straightforward. The aggregate shape of the cutting edge constitutes the actual tool condition and the measurement of wear on one or more parts of the cutting edge will only provide partial and insufficient information about the tool condition.

Most tool wear monitoring systems involve sophisticated sensors [1], which make them cost-inefficient and virtually unavailable for real applications. However, human operators can easily assess tool wear by simply inspecting the machined surface or even by listening to the sounds generated during the machining process. This has led to research into image and sound analysis techniques for tool wear monitoring. Various tool wear monitoring techniques are examined in [2], whereas a detailed review of image analysis techniques applied in this field can be found in [3]. In early works, the image of the tool itself is used to estimate the flank wear directly [4–6]. In direct measurement of tool wear, the cutting tool has to be moved for image capture and prior to imaging, compressed air is normally used to blow the dirt and tiny chips from the cutting edge. In such

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direct tool wear measurement systems, the image capturing device needs to be more complex and but captured images do not provide comprehensive information about the tool condition. Some recent works have shown that the texture of machined surfaces is also a good indicator of tool wear [7].

There is a very close correspondence between the geometrical features imposed on the machine tool by wear and micro-fracture, and the geometry imparted by the tool on to the workpiece surface. A machined surface carries a lot of valuable information about the process including tool wear, built-up edge and vibrations. Under stable machining conditions, the surface texture changes remarkably due to the changes in the cutting tool shape caused by wear. Since the cutting tool operates directly on the workpiece during a machining operation, it affects the texture of the workpiece surface which in turn provides reliable and detectable information to categorize the condition of the tool. Consequently, a machined surface is a replica of the cutting edge which carries valuable information related to the tool condition (i.e., sharpness or bluntness). Any technique for estimating the tool condition by analyzing the changes in texture of the machined surface has the advantage that its application is simpler than direct measurement methods and can be applied in different ways such as:

i *on-line application* – such as in machining of long shafts where a camera can follow the just generated machined surface.
ii *on or off-line application* – carried out after machining of each part.
iii *off-line application* – carried out after machining a number of components.

Fig. 1 shows images of steel surfaces produced by machining operations (turning operations) at two different levels of tool wear. It can be seen that the surface texture changes greatly as the tool wears. In this paper, we present some texture analysis based methods that have been successfully applied to determine the condition of cutting tools such as turning tools, end face milling tools, etc. These methods are essentially used to distinguish between the surfaces machined by a tool experiencing different levels of tool wear. Such methods are sensitive to image quality which is in turn is affected by many factors, such as non-uniform illumination, the lack of focus and magnification of the image capture device, etc. The organization of this paper is as follows. In Section 2, we discuss pre-processing of images of machined surfaces. A detailed discussion about texture analysis methods used for machine tool condition monitoring is presented in Section 3. The experimental setup is presented in Section 4 while the results presented in Section 5. We provide our conclusions in Section 6.

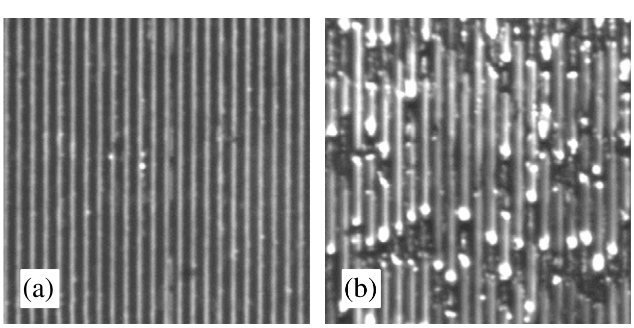

Fig. 1. Images of surfaces produced by a turning operation when the tool is (a) sharp and (b) later when the tool becomes dull.

2. Pre-processing of surface texture images

Unlike images captured in laboratory environments where factors that affect the image quality are well controlled, images of machined surfaces captured in real industrial environments often suffer from several problems including:

- *Non-uniform illumination.* A single incandescent lamp used to illuminate a machined surface can cause uneven illumination. The highly reflective nature of metal surfaces can also pose problems. The non-uniform illumination problem can be reduced by using a more sophisticated illumination system such as ring of LEDs.
- *Depth of focus.* For some machining processes, such as turning operations, the machined surface is not flat which causes some parts to be out of focus (i.e., blurred). Incorrect camera settings can also cause similar problems.
- *Image noise.* Image noise comes from undesired illumination sources, cutting chips, coolant and small particle on the surface.

Image segmentation (e.g., edge detection) and image enhancement (e.g., image filtering) techniques can be used to overcome some of these problems. In the following subsection, we discuss an illumination compensation method.

2.1. Illumination compensation

The illumination condition is far from ideal in most visual inspection systems. In [8], the problem of smoothly varying illumination is alleviated by using polynomial and spline surface fitting to estimate the radiation component. León [9] uses a data fusion technique to restore a high quality image from a series of images that are captured under various illumination conditions. In [10], homomorphic filtering is used together with normalized convolution to correct the inhomogeneity of MRI images. Homomorphic filtering is a well-accepted tool for illumination compensation [11] and makes use of a simple multiplicative image model.