Measurement 43 (2010) 1240–1249

Contents lists available at ScienceDirect

Measurement

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

Characterization of surface defects in fast tool servo machining of microlens array using a pattern recognition and analysis method

C.F. Cheung [a,*], K. Hu [a,c], X.Q. Jiang [b], L.B. Kong [a]

[a] Key State Laboratory in Ultra-precision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[b] Centre for Precision Technologies, University of Huddersfield, Huddersfield HD1 3DH, UK
[c] Department of Instrumentation, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, People's Republic of China

ARTICLE INFO

Article history:
Received 27 July 2009
Received in revised form 5 May 2010
Accepted 30 June 2010
Available online 6 July 2010

Keywords:
Surface characterization
Surface measurement
Freeform optics
Structured freeform surfaces
Microlens array
Ultra-precision machining
Fast tool servo
Pattern recognition

ABSTRACT

Microlens array (MLA) is a type of structured freeform surfaces which are widely used in advanced optical products. Fast tool servo (FTS) machining provides an indispensible solution for machining MLA with superior surface quality than traditional fabrication process for MLA. However, there are a lot of challenges in the characterization of the surface defects in FTS machining of MLA. This paper presents a pattern recognition and analysis method (PRAM) for the characterization of surface defects in FTS machining of MLA. The PRAM makes use of the Gabor filters to extract the features from the MLA. These features are used to train a Support Vector Machine (SVM) classifier for defects detection and analysis. To verify the method, a series of experiments have been conducted and the results show that the PRAM produces good accuracy of defects detection using different features and different classifiers. The successful development of PRAM throws some light on further study of surface characterization of other types of structure freeform surfaces.

1. Introduction

In the recent years, the non-conformal and micro-structural optics, or freeform optics are emerging since they possess optimum optical performance and miniaturized configurations. The freeform optics are widely used in the photonics and telecommunication industry for the design and production of high-value-added products such as head and tail automotive lighting systems, the optical pick up of holographic elements used in optical memory disks, F-theta lenses used in laser beam printers and scanners, microgroove components used in the fabrication of micro-grating and micro-grating lenses for LCD TV, PDA, etc., head mounted displays used in virtual reality applications, progressive lens inserts and fibre optic connectors.

Structured freeform surfaces are a type of freeform surfaces. They are small scale topologies which are classified as micro-grooves, microlens arrays, pyramids, lenticulations, etc. They are critical components that are widely used in photoelectrical products such as backlight guides for display devices, microlens scanners [1,2], or microlens arrays for Flat-Panel Devices, and are applicable for optical communications, optical data storage, digital displays, and laser beam shaping.

Although ultra-precision machining based on fast tool servo (FTS) machining provides a solution for machining structured freeform surfaces with sub-micrometer form accuracy and nanometric surface finish without the need for any subsequent post-processing, our understanding of the characterization of surface quality for structured freeform surfaces are still far from complete. Structured freeform surfaces are usually characterized by their surface quality such as surface roughness as well as by their optical

* Corresponding author. Tel.: +852 27667905; fax: +852 23625267.
E-mail address: mfbenny@inet.polyu.edu.hk (C.F. Cheung).

0263-2241/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.measurement.2010.06.003

properties such as their modulation transfer function (MTF). Most previous research work on micro-optics testing is based on interferometric methods [3–8] and wavefront measurement such as Mach–Zehnder interferometers (MZI) [2–10]. Some research work has been found in the application of 2D Discrete Fourier Transform (DFT) of the interference microscope image to evaluate the fabricated grid surface [11]. However, the interferometric testing of micro-optics incurs certain difficulties due to their small dimension such as Fresnel diffraction artefacts, coherent noise as well as distributing interferences [8]. On the other hands, they fail to articulate the surface quality of the structured freeform surfaces to the functional specifications of the micro-optics systems.

Microlens array (MLA) is a type of structured freeform surface which is a very important optical component in optoelectronic devices and modules, which have many potential applications. The typical functions of these refractive MLA applications are focusing, illuminating and imaging. Its surface damages and failures often cause trouble of complete system [12]. Conventionally, visual inspection of MLA is done manually. It is well known that manual inspection is suffered from subjectivity, human mistakes, slow inspection process and less consistent, whereas automatic inspection systems eliminate the subjectivity aspects and provide fast quantitative dimensional assessments. When they are applied at each appropriate step of the assembly process, they can reduce rework costs. All of these mean better quality at a lower cost. Undoubtedly, the automation of visual inspection increases the productivity and improves product quality. As a result, this paper attempts to propose a pattern recognition and analysis method for the characterization of the surface quality of structured freeform surfaces, the method is used to characterize the surface quality in terms of surface defects determined in FTS machining of microlens array.

2. Pattern recognition and analysis method (PRAM)

Fig. 1 shows a schematic diagram of the pattern recognition and analysis method (PARAM). In the PRAM, an analysis is first conducted to study the surface defects of the structured freeform surfaces and hence the proper attributes or features that differentiate the defects, feature parameters for classification, segmentation and recognition are determined. Various feature extraction and classification techniques [13] have been suggested in the past for the purpose of image analysis. The traditional approaches to image analysis include multi-channel filtering features, fractal based features and co-occurrence features [14]. Haralick's texture parameters are chosen as the most effective feature parameters [15]. More recently, methods based on multi-resolution or multi-channel analysis such as Wavelet transform and Gabor filters have gained a lot of attention for image analysis such as classification and recognition and related applications. The wavelet transform decomposes the given image to three directional components, i.e., horizontal, diagonal and vertical detail sub bands in the direction of 0°, 45° and 135°, respectively apart from the approximation (or) smooth subband. This limits the application of wavelet transform for rotation invariant texture analysis. It is believed that Gabor features are more appropriate in the context of our application. Gabor filters provide a mechanism for obtaining some degree of invariance to intensity due to global illumination, selectivity in scale, as well as selectivity in orientation. Basically, they are orientation and scale tunable edge and line detectors. In the present study, the Gabor filters are selected as the basic image feature detectors due to their good performance in many pattern recognition applications. The image features are used to formulate the patterns.

In order to recognize the patterns of defects on the MLA, a modified back propagated (BP) algorithm has been built for training an Artificial Neural Network (ANN) which is capable of analyzing topology of ANN and ways how to select its train parameters. The trained BP neural network is used to recognize and analyze the surface defects. Since it is difficult to obtain samples of surface defects to train the ANN, Support Vector Machine (SVM) that is based on statistical learning theory (SLT) is employed in surface defects detection. Compared with the training results of BP neural

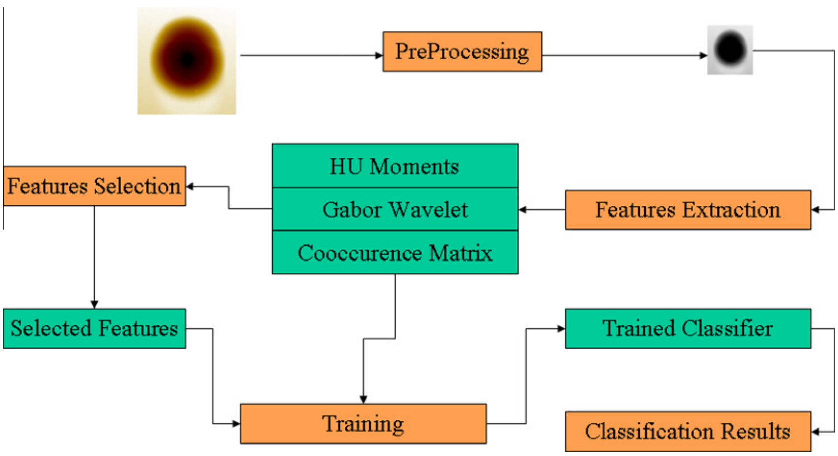

Fig. 1. A schematic diagram of the pattern recognition and analysis method.