Influence analysis of microscopic image quality in surface topography measurement with Focus Variation

Yingzhong Tian[1], Wenjun Zhang[1], Ji Qi[1], Tinggang Jia[2],Long Li[1,*]

[1]School of Mechatronic Engineering and Automation, Shanghai Key Laboratory of Intelligent Manufacturing and Robotics, Shanghai University, Shanghai 200072, CHINA

[2]Shanghai Electric Group Co., Ltd, Shanghai 200072, CHINA

troytian@shu.edu.cn

* Corresponding author: lil@shu.edu.cn

Keywords: Measure strategies, Microscopic image quality, Surface metrology, 3D model construction

Abstract. Focus variation is an optical contact-free method that allows the measurement of 3D surface metrology using optics with limited depths of field and vertical scanning. It was documented in the ISO 25178-6 for the first time in 2010. Based on this method, two categories of typical instruments are described in two aspects: hardware part and software part. The latter part is the core technology of focus variation, including image fusion, 3D model construction and image mosaic, which are closely related to the key parameters used in the process of measurement such as exposure time, contrast and analyser. In this paper, two groups of applications were selected to demonstrate the capabilities of the instruments using different measurement parameters including measurements on cutting-insert tools, stainless steel ball, stepped workpiece, reference specimens and so on. Some principles were concluded for optical 3D surface measurement with focus variation after comparing the practical results with different parameters, serving as measurement strategies.

Introduction

Surface texture plays a vital role in the functionality of a component. It is estimated that surface effects cause 10% of the failure of manufactured parts and can contribute significantly to an advanced nation's GDP. In the last century, surface texture was primarily measured by a method that involved tracing a contacting stylus across the surface and measuring the vertical motion of the stylus as it traversed the surface features. This technique has a solid researching foundation and a wide range of applications, but bringing drawbacks that the stylus can easily damage the surface, the efficiency of measurement is low and so on[3,4].

In recent years optical free-contact techniques for three-dimensional surface metrology have become increasingly important in contrast to traditional tactile measurement methods. Compared to other optical methods, focus variation is very new in the field of measuring surface texture although its principle was first published in 1924[1]. This method was documented in the ISO-25178 series first time in 2010 and the nominal characteristics were documented in 2011[2].

This paper was organized as follows: Section 2 presents the principle of focus variation technology and the operating principle of instruments based on it, introduced from two aspects: hardware structure and software structure. And the software structure part is divided in three steps, respectively described in details: image fusion, 3D model construction and image mosaic. Section 3 conducts two groups of experiments on a wide range of workpieces under different parameters, displays the results and reaches the corresponding conclusions. Section 4 concludes the measurement strategies and gives two verification experiments to prove the correctness of the strategies.

Focus Variation Technology

Focus variation is a method that allows the measurement of areal surface topography using optics with limited depths of field and vertical scanning. The measurement principle works as bellow: at first images with difference focus are captured, which is achieved by moving the sample or the optics vertically in relation to each other. Then for each position, the focus over each plane is calculated and the plane with the best focus is used to get a clear image. The corresponding depth gives the depth at this position[5,6].

Image fusion

Image fusion is a branch in the field of information fusion, applied to integrate complementary information from multi-focus image sequence to make the fused image more suitable for human visual perception and computer processing[9].

From transform domains, image fusion can be categorized as transforms on time domain and frequency domain. Methods based on time domain are simple, but with the drawbacks of easily causing detailed information loss, low contrast, blurring and blocking effect problem. Those based on frequency domain can perfectly solve these drawbacks and bring better effect, thus are the current major research hotspots. In this paper, a most commonly used method on frequency domain named Discrete Wavelet Transform (DWT) is adopted, which is found to have preserved different frequency information in stable form and allows good localization both in time and frequency domain[10,13]. The principle is firstly decomposing the source multi-images into a serie[1]s of low- and high-frequency coefficients on each level by conducting DWT. Then use Local Area Standard Deviation (LASD) maximum selection method to respectively fuse all the low- and high-coefficients into new fused low- and high-coefficients, which are eventually reconstructed into a fused image by using inverse DWT.

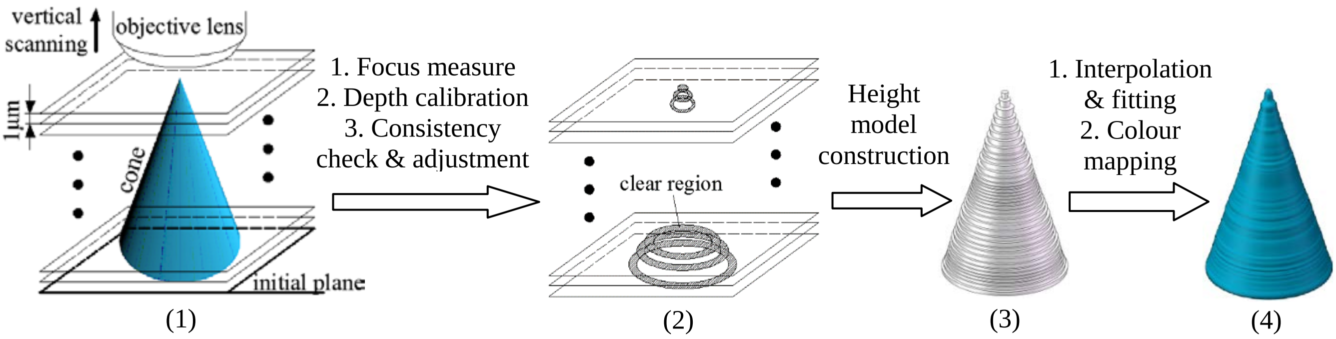


Fig. 1: The implementation procedure of 3D model construction

3D model construction

A 3D colour model can precisely reflect position, height and colour information of the microscopic surface of the measured object, and thus the step of constructing a 3D model plays a crucial role in surface topography measurement using focus variation method. The whole implementation procedure of 3D model construction, shown in Fig. 1, mainly includes four steps as bellow:

(1) The objective lens scans vertically in one direction from an initial plane to obtain absolute position information, and acquires an image when moving a fixed distance, for example, 1μm. In this way, a multi-focus image sequence can be obtained.

(2) An appropriate Focus Measure Function (FMF) is selected to calculate the contrast value between every pixel and its adjacent pixels in the image sequence. In the case of 'InfiniteFocus' equipment, standard deviation function is chosen as a FMF for its rapidity. In the image of a highly focused view, the variation of the grey values in a region is much higher and so the FMF yields higher values. The highest contrast of each pixel corresponds to the focused position, and each image in the sequence is bound to contain a focused region[4].

In addition, blurred and clear areas in a sequence are generally regional connected, which means if a pixel is in its focused position, then the other adjacent pixels are very likely to be in focused position as well, so it's very necessary to conduct consistency check and adjustment.

(3) A layered height model is constructed after processing on output data of (2).

(4) The height model is further improved by conducting interpolation and fitting to acquire the surface smoothness. Due to this model has no colour information, the colour values of those pixels with highest FMF are directly mapped to the corresponding positions on this model[14].

Image mosaic

Image mosaic is necessary when one view of the objective lens fails to contain the whole detected area for its large magnification. Image registration and image fusion are two core technologies in this step[12].

The objective lens or the sample moves horizontally to capture an image sequence in different views but with the prerequisite that every two adjacent views should have an overlapped region which is big enough for further processing. Then image registration is launched on the sequence, which will directly affect the quality of the mosaic results. Finally, the processed image sequence is fused to an integrated one, which contains adequate information of all regions in 2D image or 3D model.

Experiments and results

In this group of experiments, a series of parameters of 'InfiniteFocus' will be adjusted for times, in order to finally find the best combination of parameters for different workpieces. The parameters include: exposure time, contrast value, magnification, focal length, saturation value, use of SmartFlash mode, use of polarizer and so on.

The detection of cutting-insert tool

Fig. 2 shows the detected workpiece and some of the observed results under different parameters, and all the relevant parameters and result assessments are displayed in Table 1. Fig. 2(a) is the cutting-insert tool and Fig. 2(b) is the enlarged view of wear on the major cutting edge. Finally, appropriate measurement strategies of this kind of workpiece will be concluded.

It's safe to draw the conclusion from Table 1 that when this wear on tool major cutting edge is detected, magnification should be adjusted to 10X to capture more information.

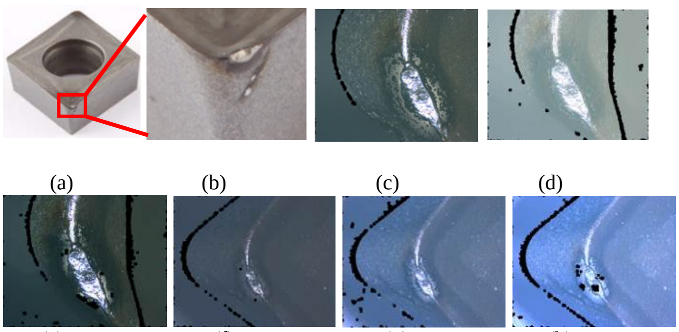


Fig. 2: wear on cutting-insert tooling and the figures under different parameters. (a) cutting-insert tool; (b) wear details of cutting insert tool on the major cutting edge; (c~h) the observed figures of the wear under different parameters. And relevant parameters and result assessment of each figure are shown in Table 1.

Table 1: parameters and result assessments of different tests

N(m)	E t (ms)	C	M	I p	E
1(c)	1.66	1	10X	N	Clear
2	1.75	1	10X	N	Clear
3(d)	2	0.43	10X	N	Low contrast
4(e)	2	1.5	10X	Y	Invalid points exist
5(f)	2.44	1	5X	Y	Invalid points exist
6	2.55	0.43	5X	Y	Invalid points exist; low contrast
7(g)	4.88	1.6	5X	N	Clear
8(h)	6	2	5X	Y	Invalid points exist; colour distortion

In Table 1: N-Table number; m-Figure number; E t-Exposure time; C-Contrast; M-Magnification; I p-Invalid points; E-Effect; S f-SmartFlash; Y-Yes; N-No. The abbreviation rules will also apply to those in the following tables.

Meanwhile, considering the fact that when exposure time is fixed at 2ms, relatively low contrast like 0.43 in Fig. 2(d) leads to an insufficient contrast of colour, and high contrast like 1.5 in Fig. 2(e) leads to more invalid points (black), which means useful information is lost, exposure time should be adjusted to less than 2ms and better contrast is 1, thus a clear view with high contrast can be acquired, shown in Fig. 2(c). When both worn and unworn regions are detected, magnification is increased to 5X. More exposure time and higher contrast in Fig. 2(f)&(h) bring more invalid points on the wear. There will be no invalid points on a whole when exposure time is around 5ms and contrast is around 1.6 in Fig. 2(g).

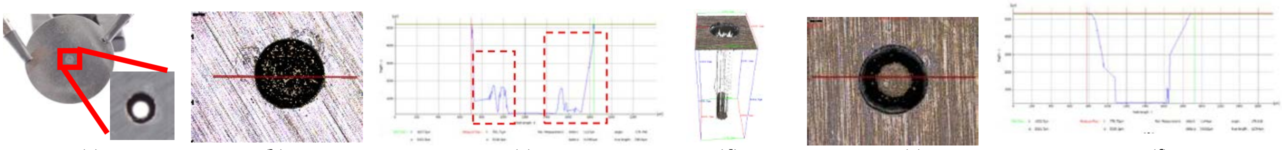
Table 2: parameters and result assessments of different tests

N(m)	E t (μs)	C	M	I p	S f	E
1(b)	194	1.5	10X	N	N	Too bright in Central part and too dark in surrounding region
2(c)	399	2.17	10X	Y	N	Ditto; invalid points exist
3(d)	199	1	10X	N	Y	Clear

The detection of through hole

The enlarged view of through hole shown in Fig. 3(a) has a small end with radius of 338μm and a big end with radius of 569μm.

In order to check the profile of the through hole, a profile path in red across the diameter of both small end and big end is used. And the profiles of surface are generated. For the profile of the small end is almost the same as the profile of the big end, so it's not presented here. From the profile of the big end, conclusion can be draw from it. The data in red rectangles reflects that when a tilted surface with a big angle is detected, the data may be distorted if the angle exceeds the limitation of the instrument. Additionally, in the Fig.3(b), the hole is full of invalid points. In this test, the angle of obliquity is 87.5°.



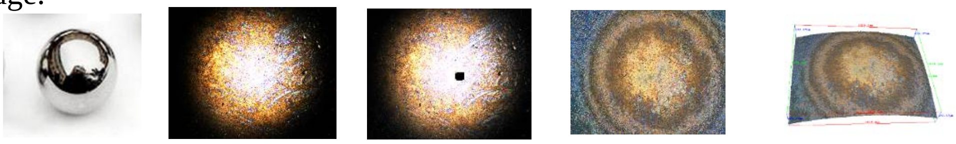
(a) (b) (c) (d) (e) (f)

Fig. 3: through hole and the figures with relevant profiles under different parameters.(a) workpiece with through hole; (b&c) big end of the hole and the profile generated; (d) 3D model; (e&f) big end of the hole and the profile generated with SmartFlash open.

The test of Fig. 3(b) is without SmartFlash. In Fig. 3(e), when SmartFlash is open, a comparatively smoother profile with a much better effect can be acquired with less information distortion. But still, it's not an accurate result. The value of contrast is 1 in all the tests, and the variation of exposure time has no obvious influence on the results.

The detection of spherical surface with high reflectivity

The spherical surface of the stainless ball in Fig. 4(b) is featured by decreasing reflectivity from the centre to the edge.



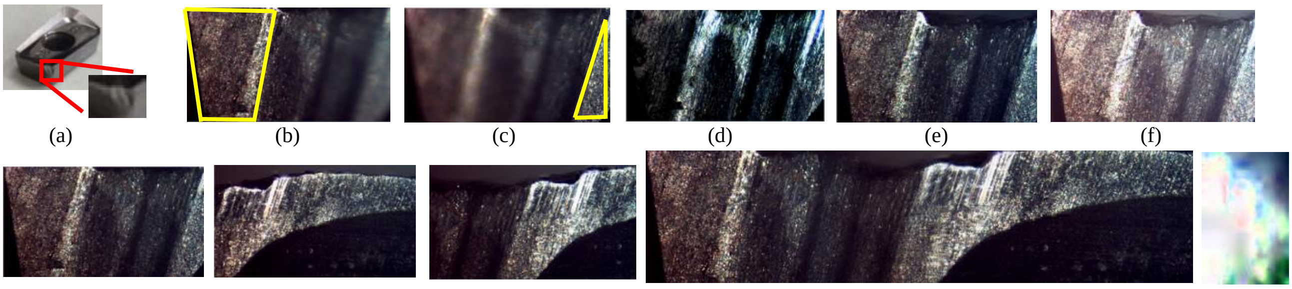
(a) (b) (c) (d) (e)

Fig. 4: a stainless ball and the figures under different parameters.(a) a stainless ball; (b~d) the observed figures of the spherical surface under different parameters; (e) 3D model. And relevant parameters and result assessment of each figure are shown in Table 2.

When a spherical surface is detected with SmartFlash off, it can only display a small region surrounding the centre of the ball in Fig. 4(b) and Fig. 4(c). The exposure time and contrast used don't have an obvious influence on the figures in which the central region is too bright, as a result of high reflectivity. After the SmartFlash is open, much better result is shown in Fig. 4

The detection of cutting-insert tool

In this experiment, a cutting-insert tool in Fig. 5(a) is detected to observe its microscopic surface topography of the wear, which is featured by its angular and undulating surface and low reflectivity. After setting the magnification to 5X, a multi-focus image sequence is acquired, two image of which is shown in Fig. 5(b)&(c). The regions in yellow are clear and others are blurred.



(a) (b) (c) (d) (e) (f)

(g) (h) (i) (j) (k)

Fig. 5: wear on cutting-insert tooling and its relevant figures. (a) cutting-insert tool with enlarged view of the wear; (b&c) images in a multi-focus image sequence (clear region is in yellow); (d~g) fused images of the wear under different parameters; (h&i) fused images of the wear in different views; (j) mosaic result of Fig. 9(g), (h)&(i); (k) colour distortion in image fusion caused by overexposure phenomenon. And relevant parameters and result assessment of each figure are shown in Table 3.

Table 3: parameters and result assessments of different tests

N(m)	E t (ms)	M	F	A	P	E
1(b)	200	5X	B	N	N	Slight loss of information
2(c)	200	5X	D	N	N	Clear
3(d)	200	80X	B	N	N	Loss of information in tiny holes
4(e)	200	80X	D	N	N	Clear

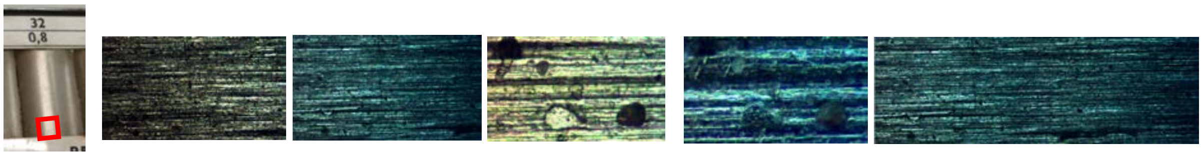
In Table 3: F-Field; B-Bright field; D-Dark field; A-Analyzer; P-Polarizer; oep.-overexposure; info.-information. The abbreviation rules will also apply to those in the following tables.

Conclusions

By using the strategies concluded for the metallurgical microscope system, a verification experiment on reference specimens of grinding is conducted to verify the correctness of the conclusions. The block of reference specimens of grinding with Ra 0.8, shown in Fig. 6(a), is featured by its cylindrical surface, with high reflectivity in the middle.

Firstly, in order to detect the surface shape of the block, a small magnification of 5X is used, and the effect of Fig. 6(c) using dark field has obvious advantages over that of Fig. 13(b) using bright field. The mosaic result of Fig. 6(c) and another image under the same parameters is shown in Fig. 6(f), which brings a good effect and a broad vision. Afterwards, the magnification is set to 80X to capture images of the metallographic structure on the surface. For there are information losses occurred in some holes of Fig. 6(d), a compensatory test is launched to offer the lost information in the holes, shown in Fig. 6(e).

All the results are in line with the strategies, which verify the correctness and practicability of the strategies.



(a) (b) (c) (d) (e) (f)

Fig. 6: reference specimens of grinding and its relevant figures. (a) reference specimen of grinding with Ra 0.8; (b&c) fused images of the texture on the block under different parameters in magnification of 5X; (d&e) fused images of the texture on the block under different parameters in magnification of 80X; (f) mosaic result of Fig. 6(c) and another image under the same parameters. And relevant parameters and result assessment of each figure are shown in Table 4.

Table 4: parameters and result assessments of different tests

N(m)	E t (ms)	M	F	A	P	E
1(d)	500	5X	D	N	N	Lose of low brightness information; serious oep. phenomenon exists
2(e)	500	5X	B	Y	Y	Slight loss of low brightness information;
3(f)	800	5X	B	N	N	High contrast; with adequate info.; serious oep. phenomenon exists
4(g)	500	5X	B	N	N	Clear
5(h)	500	5X	B	N	N	Clear
6(i)	500	5X	B	N	N	Clear

Acknowledgments

This research work was supported by National Key Technology Support Program of China (Grant No. 2015BAF10B01) and Science and Technology Commission of Shanghai Municipality (Grant No.15111104002 & 15111106302).

References

[1] von Helmholtz, H.L.F.: Helmholtz's treatise on physiological optics. Optical Society of America[J] (1924).

[2] ISO 25178-6(2010): Geometrical product specifications (GPS) -- Surface texture: Areal -- Part 6: Classification of methods for measuring surface texture. International Organization of Standardization.

[3] R. Leach: Optical Measurement of Surface Topography[M], Springer, Heidelberg (2011).

[4] R. Leach: Fundamental Principles of Engineering Nanometrology[M], William Andrew, Oxford (2009).

[5] R. Danzl, F. Helmli and S. Scherer: Focus variation–a new technology for high resolution optical 3D surface metrology[C], the 10th International Conference of the Slovenian Society for Non-Destructive Testing; Ljubljana, Slovenia (2009).

[6] R. Danzl, F. Helmli and S. Scherer: Automatic measurement of calibration standards with arrays of hemi-spherical calottes[C], the 11th Int. Conf. Metrology and Properties of Engineering Surfaces, Huddersfield, pp. 41–46 (2007).

[7] Niederöst, M., Niederöst, J., Scucka, J.: Automatic 3D reconstruction and visualization of microscopic objects from a monoscopic multifocus image sequence. International Archives of the Photogarmmetry, Remote Sensing and Spatial Information Sciences, 2003, XXXIV 5/W10, 1682–1777.

[8] Nayar, S.K.: Shape from focus. Department of Electrical and Computer Engineering, The Robotics Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213 (1989)

[9] Al-Azzawi Nemir, et al.: Medical image fusion scheme using complex contourlet transform based on PCA[C], IEEE Engineering in Medicine and Biology Society. Conference, 2009, Vol.2009 , pp.5813-6.

[10] Yufeng Zheng: Multi-scale Fusion Algorithm Comparisons: Pyramid, DWT and Iterative DWT, 12th Int. Conf. on Information Fusion. pp. 1060-1067, 2009.

[11] Yuemei Xu: Study on Multi-Focus Image Fusion Based on Multi-Scale Transform[D], China Uni. Of Mining and Technology. pp. 35-55, 2012.

[12] Chengcheng Liu,Yong Shi: Scene Image Mosaic Based on Three Freedom Degree[J], Procedia Computer Science, 2013, Vol.17 , pp.62-69.

[13] Gonzalo Pajares, et al.: A wavelet-based image fusion tutorial[J], Pattern Recognition, 2004, Vol.37 (9), pp.1855-1872.

[14] Ikhyun Lee and et al.: Adaptive window selection for 3D shape recovery from image focus[J], Optics & Laser Technology, 2013,Vol.45, 21–31.