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Chromatic focus variation for surface metrology

Aalim M. Mustafa[1], Hussam Muhamedsalih[1], Dawei Tang[1], Prashant Kumar[1], Jane Jiang[1]

[1]*EPSRC Future Metrology Hub, University of Huddersfield, UK*

H.Muhamedsalih@hud.ac.uk

Abstract
Optical metrology plays a vital role in a wide range of research and inspection areas in the industry. The focus variation instrument is a popularly adopted method for additively manufactured parts because it can measure steep surfaces with very high slopes and irregularities. The contrast/sharpness between the neighbouring pixels is used to determine the image focus position, and hence the surface height is obtained. In traditional focus variation instruments, a piezoelectric actuator (PZT) is used for mechanical scanning in image capturing. The slow mechanical movement is a limiting factor for fast measurement in modern advanced manufacturing applications. Another issue associated with the traditional focus variation instruments is the nonlinear hysteresis motion of PZTs and their physical size. To overcome the above limitations, we propose a chromatic focus variation method to axially shift the focus along the optical axis without any mechanical movement using a wavelength scanning mechanism combined with a chromatic objective lens. This work presents initial measurement results obtained using the proposed system and its comparisons with the commercial Alicona focus variation system.

Keywords: Chromatic Lens, Scanning, Focus Variation, Metrology, Roughness.

1. Introduction

Surface metrology instruments are used to measure various surface features to ensure that they meet the required specifications. The focus variation technique has proved its capability to measure rough, steep surfaces with very high slopes; hence, it is widely used for measuring additively manufactured surfaces [1-3].

Nayar and Nakagawa [4] originally proposed the focus variation technique in 1994. They named the technique “Shape from focus,” referring to the process of extracting the surface shape and texture from the degree of focus in the captured images. The process starts with acquiring a series of images by moving either the sample or the objective lens with respect to each other in the vertical direction. The current focus variation instruments use piezoelectric actuators (PZT) for this purpose. Figure 1(a) presents a traditional focus variation system (FVS) schematic. The number of stack images captured depends on the total travel range of the PZT can travel and the stops it makes to capture each image. Once the images are obtained, each pixel from the images is analysed to generate a 3D depth map of the sample. Continuous research on the focus variation method has led to further progress in developing different variants for the measurement of surface topography [5-8].

One of the problems in the focus variation instrument is the mechanical movement of the objective lens using the PZT during the scanning process. The limited speed of PZT scanning, the physical size, the weight of such actuators, and a nonlinear hysteresis of their motion [9,10] can complicate the system and slows down the entire measurement process. This research aims to replace the mechanical scanning process by implementing chromatic scanning, i.e. shifting focal positions of the beam along the optical axis with changing wavelengths. With a non-PZT scanning system in place, the chromatic focus variation system will lot be simpler and faster in operation. Chromatic scanning using a chromatic lens has been reported previously in confocal microscopy [11] and in 3D structured light sensing [12], but it is for the first time we are reporting the implementation of chromatic sensing in focus variation system, and its performance comparison with the in-lab developed PZT based mechanical scanning FVS and the commercial Alicona FVS.

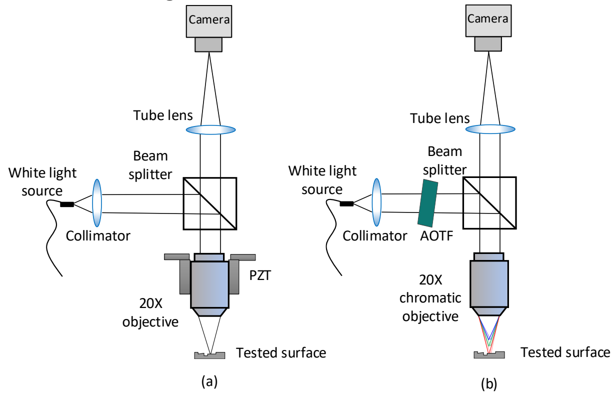

Figure 1. (a) Traditional focus variation schematic diagram, (b) chromatic focus variation.

2. Chromatic Focus Variation (CFV)

The chromatic focus variation setup is shown in Figure 1 (b). The system contains a chromatic lens in place of the bulky PZT mechanical scanning system. We used an acoustic-optic tunable filter (AOTF) to filter and tune the wavelengths within the desired wavelength scanning range. The chromatic objective lens used was designed to operate within the visible wavelength region (480-680 nm). The numerical aperture, the working distance and the magnification of the chromatic objective used are 0.4, 3 mm and 20x, respectively. An experiment was performed to obtain the focal shift of the beam with the wavelength. Light from the source is fed into the fibre optic collimator (FC). The collimated beam from FC is split at the beam splitter (BS), and a part of the beam goes to the measurement head having the chromatic objective. The reflected light from the sample was recorded using the Imperex camera (ICL-B0620M-KC000), while PZT was scanned over its full range at the set wavelengths. The standard deviation method was used to locate the best focus position from the recorded frames. Figure 2 shows a focal shift of 65 um on switching the wavelength from 642nm to 540 nm wavelength, which matches the chromatic lens's specifications.

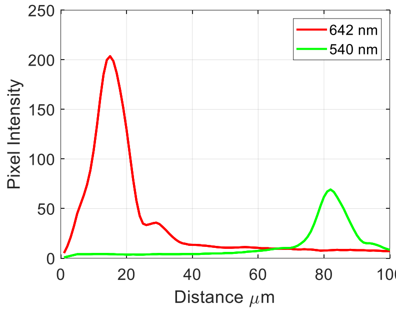

Figure 2. The focal shift between wavelengths 641 and 520 nm

3. Surface measurement

For measurement comparisons, we used the Microsurf 328 standard sample machined of vertical grinding. Using CFV and mechanical focus variation (Nikkon lens, TU plan flour 20X/0.45) setup, multiple images were recorded by scanning the wavelengths and PZT, respectively. The images were analysed using Matlab software, and the standard deviation was used as a focus measure, as reported in [13]. The same sample was also measured using the commercial Alicona Focus Variation System (AFVS). The three instruments used 20X magnification lenses, but Alicona's image with 20x objective has three times larger FOV than the lenses used in our CFV. Hence, we cropped similar matching region from the results for comparison. The 3D surface measurement results are shown in Figure 3, where the same surface features present in the three methods.

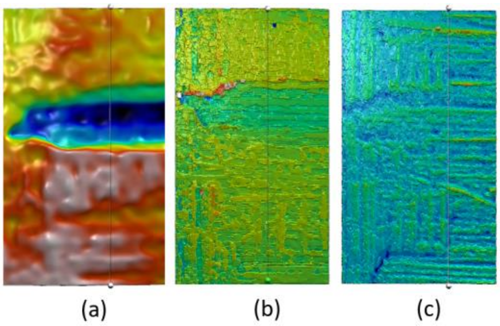

Figure 3. 3D surface measurement of the Microsurf 328 standard sample CVF, mechanical FVS and the commercial AFVS

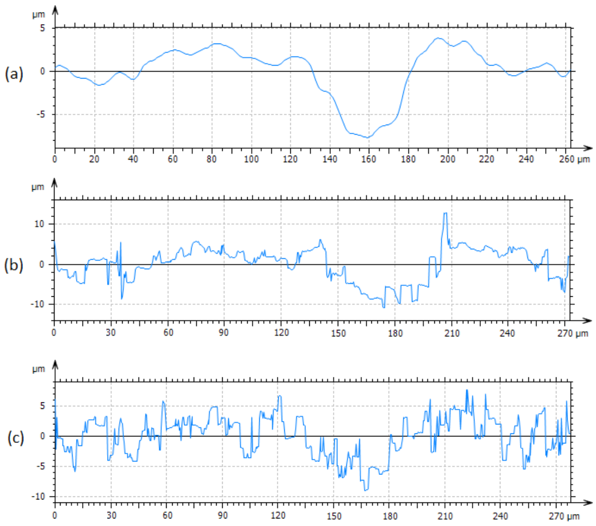

Figure 4. Profile plots of the measured sample using three different metrology instruments (a) CFV, (b) Mechanical Scanning FV and (c) AFVS.

We further plotted a 2D profile along the same line using the three focus variation instruments. The measurements obtained with our initial setup correlate well with AFVS results, where the dip (valley) can be observed in all the measurements with a depth of around eight μm. The arithmetical mean height was calculated for the measured area and the selected 2D profile using ISO 25178 and ISO 4287, respectively, as seen in Table 1. Since we didn't filter the measured data, the noise signals contributed to increasing the S_a and R_a values.

Table 1. Surface parameters of the measured sample

	AFVS	FVS	CVF
S_a (µm)	2.11	3.89	3.06
R_a (µm)	1.04	1.93	2.13

4. Conclusion

This paper proposes a chromatic focus variation instrument in which areal surface measurements are obtained by scanning a range of wavelengths instead of mechanically moving the sample or the objective lens. The obtained results were compared to a basic mechanical scanning platform and to Alicona Infinite Focus. Our simple setup did not consider optimised lighting, data filtering, or image enhancements; therefore, the results show some noise signals. A comprehensive investigation of the measurement noise is suggested in future research by comparing the instruments' transfer functions.

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References

[1] L. Newton et al. 2019 Areal topography measurement of metal additive surfaces using focus variation microscopy *Additive manufacturing* **25** 365-389.

[2] O. Flys et al. 2020 Using confocal fusion for measurement of metal AM surface texture. *Surface Topography: Metrology and Properties*, **8**, 024003.

[3] Y. Zou, J. Li, and Y. Ju 2022 Surface topography data fusion of additive manufacturing based on confocal and focus variation microscopy *Opt Express*, **30** 13 23878.

[4] S. K. Nayar and Y. Nakagawa 1994 Shape from Focus *IEEE Trans Pattern Anal Mach Intell*, 16, 8.

[5] R. Danzl et al. 2009 Focus variation- a new technology for high resolution optical 3D surface metrology. *The 10th international conference of the slovenian society for non-destructive testing*.

[6] R. Danzl et al. 2011 Focus variation - A robust technology for high resolution optical 3D surface metrology *Journal of Mechanical Engineering*, **57 3**, 245–256.

[7] F. Helmli et al. 2014 Ultra high speed 3D measurement with the focus variation method Fringe 2013: *7th International Workshop on Advanced Optical Imaging and Metrology* 617–622.

[8] K. Zangl et al. 2018 Highly accurate optical µcMM for measurement of micro holes *Procedia CIRP*, Elsevier 397–402.

[9] D. V. Sabarianand et al. 2020 A review on control strategies for compensation of hysteresis and creep on piezoelectric actuators based micro systems *Mechanical Systems and Signal Processing*.

[10] J. Gan and X. Zhang 2019 A review of nonlinear hysteresis modeling and control of piezoelectric actuators *American Institute of Physics Advances* **9** 4.

[11] Y. D. Ma et al. 2023 Applications of Chromatic Confocal Technology in Precision Geometric Measurement of Workpieces *Journal of Physics: Conference Series, Institute of Physics*.

[12] R. Ramm et al. 2022 High-resolution 3D shape measurement with extended depth of field using fast chromatic focus stacking *Optical Express*, **30** 13.

[13] S. Pertuz, et al. 2012 Analysis of focus measure operators for shape-from-focus *Pattern Recognition* **46** 5.