In-situ chromatic confocal surface profilometry employing image fiber correspondence for resolving lateral cross talk problems

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A miniaturized slit-scan chromatic confocal profilometer for in-situ microscopic surface 3-D automatic optical inspection (AOI) is developed by employing image fiber correspondence for minimizing lateral sensor cross talks and enhancing the vertical detection resolution. A fiber-based chromatic confocal method is proposed by employing linear coherent image fiber bundles to minimize the cross-talk problem. The developed method has its unique advantage in sharpening the depth resolution to be comparable to the one achieved by traditional single pinhole configuration. From the experimental test and analysis, it is verified that the maximum measurement deviation based on $\pm 3\sigma$ can be controlled well within 0.09% of the overall measurement range. However, due to the increased exposure time, the tradeoff between the temporal and vertical measurement resolution of the developed method needs to be further addressed by enhancing the image acquisition rate.

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1. Introduction

The confocal measurement utilizes the geometrical matching of two conjugate focal points corresponding to both the object surface and the point detector defined by a pinhole [1]. In traditional confocal microscopy, the potential cross-talk between neighboring sensors is commonly minimized by employing a tiny pinhole incorporating a vertical scanning process. In recent years, a chromatic confocal microscope generally equips with a broadband light source in combination with a diffractive lens as well as wavelength-to-depth coding for instantaneous line-section profile measurement of a three-dimensional surface [2-3].

A miniaturized fiber-based chromatic confocal system is proposed by employing a specially-designed chromatic dispersive objective and linear coherent image fiber bundles in a multi-wavelength line-slit optical configuration for minimizing the above cross-talk problem. The developed system consists of a chromatic confocal microscopic configuration, a pair of linear coherent image fiber array and a specially designed chromatic objective to perform surface measurement in achieving a large depth measurement range and high vertical resolution.

2. Optical Configuration of Confocal Microscopy

The optical system setup illustrates in Fig. 1(a) and (b). Each image fiber is spatially configured and employed to match a detecting incident light beam from the light source with its corresponding reflected light from an object underlying inspection, in which a spatially conjugate one-to-one relation between each incident light and its matching detected object point can be formed accurately. To minimize the above cross-talk problem, we employ the spatially matching image fiber pairs to establish one-to-one conjugate relationship between the incident fiber point and its corresponding detected pixel in the developed chromatic confocal system. It means that an optical design of a fiber core diameter and a fiber pitch, shown in Fig. 1 (c) and (d), is used to minimize the potential cross talks between the detecting sensors. The fiber is designed to spatially filter unfocused light and other possible stray lights away from the corresponding detection sensor, thereby minimizing the lateral cross talks between the detected image sensors [4].

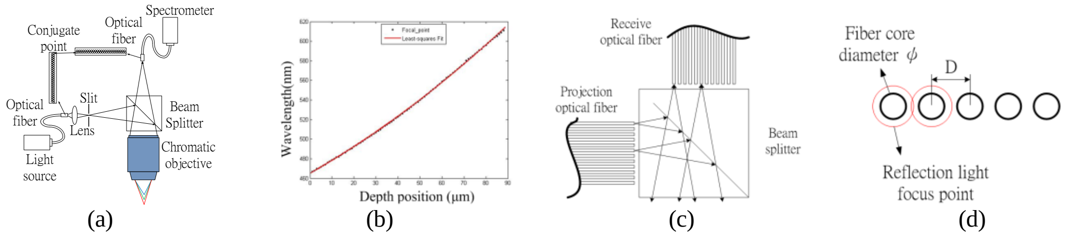

Fig. 1 Schematic diagram of the developed measurement system: (a) optical configuration and; (b) calibrated mapping curve between light wavelength and profile depth; (c) Optical configuration of fiber pairs; and, (d) optimal design of the fiber core diameter and fiber pitch.

3. Experiment Results and Analysis

To evaluate the effects of the fiber size on the FWHM of the depth response curve, a standard calibrated flat mirror was mounted on a Z axis linear stage for performing vertical scanning. By detecting the peak of the SRC, the reliability of the depth measurement on the same calibrated target surface can be shown in Table 1. The listed results here have confirmed the above conclusion concisely.

Table 1 30-time repeatability test results of SRC using various confocal filters.

	Slit (60 μm)	Fiber (62.5 μm)	Fiber (9 μm)	Pinhole(60 μm)
Standard deviation of peak position (nm)	0.8045	0.0595	0.0305	0.0144
Mean FWHM (nm)	30.200	31.853	25.570	21.140
Standard deviation of FWHM (nm)	3.214	0.836	0.693	0.667

Meanwhile, to verify the measurement accuracy using the proposed methodology, a 25.4 μm standard step-height target was employed to perform step height profile measurement. Fig. 2 and Table 2 exhibit the step measurement result. The measurement result by using the developed system was comparably close to the one achieved by the single-pinhole confocal measurement method while the measurement efficiency can be enhanced due to its multiple-point measuring configuration.

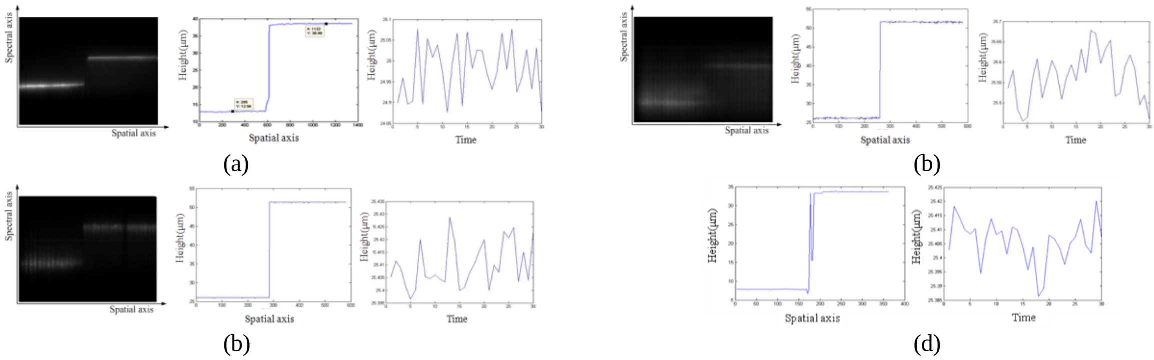

Fig. 2 Measurement repeatability results on a 25.4 μm standard step-height target: (a) slit (60 μm); (b) a linear fiber array (diameter 62.5 μm); (c) a linear fiber array (diameter 9.0 μm); and (d) a single fiber (62.5 μm).

Table 2 30-time repeatability test results on measuring a 25.4μm step-height target using various confocal filters.

	60 μm slit	62.5 μm fiber	9 μm fiber	60 μm pinhole
Average height (μm)	24.98	25.56	25.41	25.406
Standard deviation (μm)	0.066	0.061	0.009	0.0076

4. Conclusions

A chromatic confocal microscopic profilometer with aids of linear coherent fiber arrays was successfully developed to achieve in-situ line-scan surface profilometry of micro structures and minimize the lateral sensor cross-talk problem. The measurement result is comparably close to the one achieved by the single-pinhole confocal measurement method while the measurement efficiency can be significantly enhanced due to its multiple-point measuring configuration. The detection resolution of surface profilometry can reach below 0.03% of the overall detection range. The developed system can be further developed with advancement of the hardware performance such as the imaging sensor for its optimal performance in in-situ measurement.

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