In-Process 3D Roll Pattern Measurement and Inspection by Fluorescence Strobo-Stereoscopy

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ABSTRACT

This paper presents a novel method to in-process achieve 3D imaging of the roll pattern during the roll-to-roll (R2R) process. Strobo-stereoscopy that enables 3D image reconstruction by synchronously controlling the light illumination system in accordance with the rotational position of the roll was employed to in-process inspect the engraved surfaces for cracks or wear damage as well as roll roundness and rotational error due to vibration or bearing damage. Fluorescent fluid with the characteristic of stoke shift and high speckle contrast enables this system to measure reflective surface with regular pattern. The proposed fluorescent strobo-stereoscopy consists of two cameras, bandpass filters and light emitting diode-based UV illumination system, reconstructs 3D images of the roll along the circumferential direction, and then provides panoramic full-view 3D images. The developed strobo-stereoscopic measurement system covered the scanning area 100 × 100 mm^2, and showed the axial accuracy is within 5% and the lateral accuracy is within 2%. The proposed roll inspection method can be integrated with R2R machine tools in an on-machine configuration for in-process, fast, convenient 3D roll inspection.

Keywords: Strobo-stereoscopy; Fluorescence; Roll inspection; 3D Imaging; Roll-to-roll.

1. INTRODUCTION

Roll-to-roll (R2R) manufacturing as a continuous, high-volume manufacturing process has provided feasibility of printed electronics, display, and even semiconductor [1]. In particular, R2R-based printed electronics have opened new avenues for nano-to-chip scale structures or patterns made of various materials on the various substrates such as plastic, paper, silicon, etc. [1,2]. R2R measurement and inspection is of importance to achieve both high quality and productivity in R2R manufacturing. Many methods for sensing, motion controls, process control, quality control, and manufacturing system design have been introduced since a few decades ago [1-4]. In particular, most of inspection methods are focused on roll deflection measurement, web thickness measurement, alignment measurement, roll vibration, and so on. By utilizing sensors, motion control algorithms, high-precision machine tools, and new materials some process problems will likely be solved. However, the key challenge to achieve high performance R2R manufacturing is to in-process inspect the printing quality at production speed with high resolution. Unlike the previous studies to measure the pattern or structure printed on the substrate, this study focused on industrial-scale measurement and inspection methods for advancing current R2R manufacturing technologies. The patterned roll geometry was in-process inspected and monitored while the roll was rotating, and rotational error associated with the roll was also monitored.

2. MEASUREMENT PRINCIPLE

The primary method and foundation for this project is strobo-stereoscopy [5,6], as illustrated in Figure 1. While the stereoscopy is used to reconstruct the target 3D model at specific positions, stroboscopy features two operational modes (phase-locking and phase-shifting) that enable on-machine whole-view scene construction controlled by the spindle encoder signal. In a phase-locking mode, stroboscopic image can be obtained because the illuminating frequency and spindle rotating speed are the same. The phase shifting mode can be achieved by shifting the phase (time delay) under the same illumination freuqnecy and spindle rotational speed. The target rotates at a set frequency ω, and the motion control's pulse counter is used to control the phase shifter towards the stroboscopic light, which illuminates the cutting tool's specific area by blinking the input light source. The bandpass filters separate the dye's emission wavelength ($\lambda_{emission}$) with the input ultraviolet (UV) light ($\lambda_{excitation}$). The illumination system, camera system, and spindle system can all be synchronized and programmed using a motion controller. Measurement operations are automated using digital signal processing.

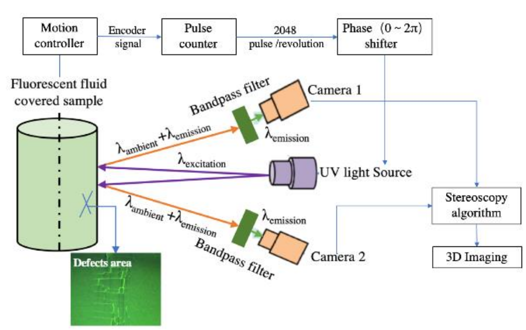

Figure 1. Fluorescent Strobo-Stereoscopy method working principle.

Table 1. Scanned comparison results between FSS method and LDS method (Unit: mm).

Method	Length 1	Length 2	Ave. length	Depth 1	Depth 2	Ave. Depth
LDS	4.12	4.02	4.07	0.21	0.22	0.215
FSS	4.08	3.95	4.015	0.21	0.21	0.21
Variation	1%	1.7%	1.4%	0	4.5%	2.3%

3. RESULTS

The proposed FSS approach is demonstrated by using a square-patterned structure as the target. The results of the laser displacement sensor (LDS) measurement are applied as the reference, and the single surface reconstruction results collected by FSS are compared to them, which is presented in Table 1. The variation is less than 2%, and variation in depth is less than 5%.

Additionally, Figure 2 (a) illustrates this linear scan comparison on a single image. Furthermore, to demonstrate the capabilities of the complete view reconstruction, a surface scan is performed on a ø2" rod with the same patterned structure (Figure 2 (b)). Before the cylinder reconstruction process begins, an extended map is stitched using the specified rotation angle information for each individual reconstructed image.

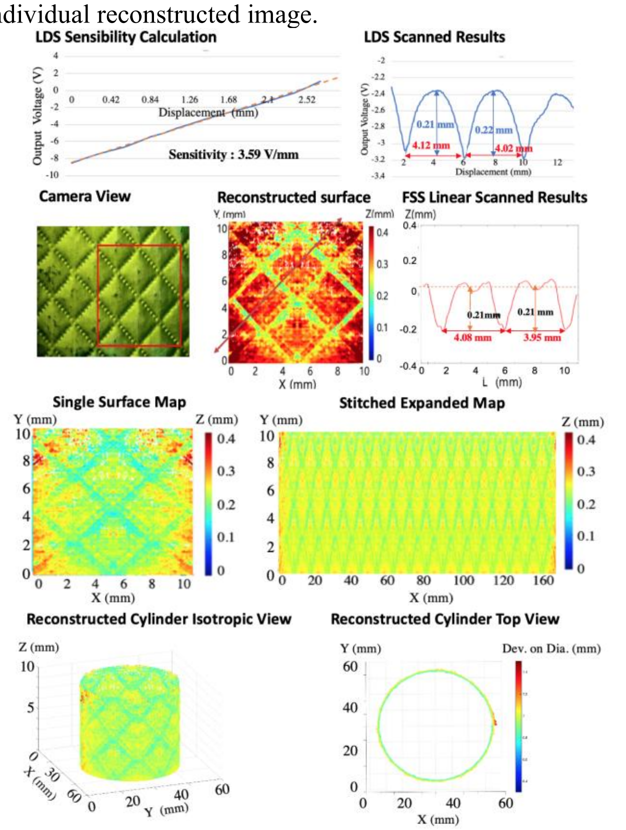

Figure 2. Single surface measurement comparison (top) and whole view reconstruction results (bottom) [6].

The lateral resolution of the proposed stroboscopy will be assessed with the standard sample as a further work. Also, the limitation of use of fluorescence dyes for surface metrology will be characterized.

4. CONCLUSION

The stroboscopy assists the scan on fast rotating objects, and benefit with the fast reconstruction and easy composition of the stereoscopy algorithm, this paper proposes a feasible solution for Roll-to-roll (R2R) inspection, namely the fluorescent strobe-stereoscopy (FSS) method, in which the fluorescent fluid decreases the specular reflection effect. A demonstration experiment was conducted with square-patterned structure. Compared to the laser displacement sensor's results, the variation in axial and lateral direction is within 5% and 2% respectively. Furthermore, a whole view reconstruction of the cylinder structure was completed.

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