Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Digital Speckle Pattern Interferometer for Measuring Micro Deformation Area

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1. Introduction

Nondestructive testing(NDT) and inspection of structural materials are becoming increasingly important to assure the safety level in the present industries. Nondestructive measuring techniques using an optical interferometer have emerged as a valuable tool for many industrial applications [1]. This non-contact optical method is a full-field measurement technique with high speed [2].

Recently, by virtue of the development of electronic technologies, a digital speckle pattern interferometer (DSPI) has been highly developed and widely used in many engineering applications to measure the deformation area of objects. The great advantage of this system is that the data processing can be done easily in real time and can provide highly accurate deformation data by using phase-analyzing techniques.

In this paper, a DSPI based on remote communication is developed on a movable table for measuring 3D deformation of an object. Wrapped phase data of the deformed area can be measured by acquiring phase-shifted fringe images. The 3D deformation phase image can be extracted by applying an unwrapping algorithm to the wrapped phase data. Usually, many impulse pattern noises are included in the acquired wrapped phase image because these are produced from the interfered speckle pattern fringes. We developed an efficient phase unwrapping algorithm by developing an efficient removing filter. This filter is designed and applied to a phase map image that efficiently removes impulse noises. The filter improves the extracting efficiency of the phase information around the wrapping area. A fast unwrapping algorithm based on the discrete cosine transform (DCT) is adopted [4]. The hardware and software configurations of the developed DSPI are described in this paper.

2. Developed digital speckle pattern interferometer

A photograph and the hardware configuration of the developed DSPI are shown in Fig. 1 and Fig. 2, respectively. This system is configured to measure a deformation in the in-plane or out-of-plane direction of a specimen by controlling the SW block. The system is built on an movable optical table by using optical components with a CW laser (532 nm, Samba-150, Cobolt), a PZT actuator (P-841.10, PI) with a controller controlled by RS232 communication (E-662, PI), a CCD camera controlled by USB communication (ARTCAM-098, ARTRAY) and a notebook computer

When each coherent laser beam is projected onto the surface of a specimen after passing it through a beam expander, then a speckle pattern speckle image will be generated for the surface of an object. The computer acquires the speckle image by using a CCD camera. To measure precise deformation, the 4 phase maps algorithm with each phase shifting by 90 degrees is adopted because it is robust for noises [3].

The wrapped phase map of φ_d for a deformed area can be acquired by subtracting φ_a from φ_b according to equation (1),

$$\phi_d = \phi_a - \phi_b \qquad (1)$$

Here, the φ_a are φ_b are the phase maps before and after deformation, respectively.

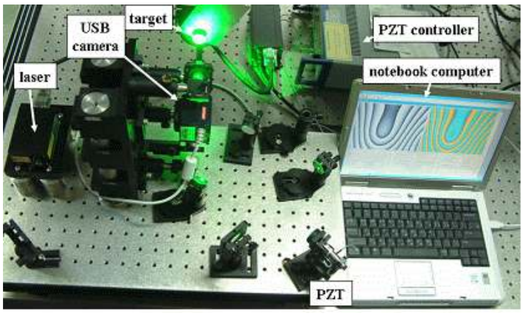


Fig. 1 Photograph of the configured digital speckle pattern interferometer

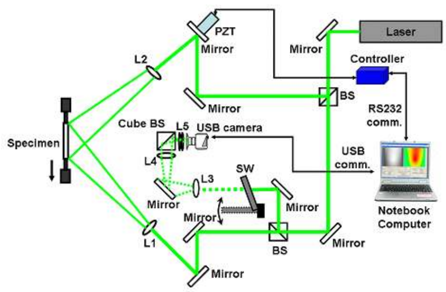


Fig. 2 Configuration of the digital speckle pattern interferometer

3. Signal Processing for a digital speckle pattern interferometer

The signal processing procedure to extract a wrapped phase image and a 3D phase image are shown in Fig. 3 and Fig. 4, respectively. A ∏-shift filter is applied to a raw wrapped phase map to improve the noise reduction efficiency. We designed a ∏-shift filter with a low-pass filter which is designed in frequency domain. This filter improves the system performance because this filter efficiently removes the impulse noises existing nearby the wrapping positions where the noises could cause large errors during the unwrapping procedures.

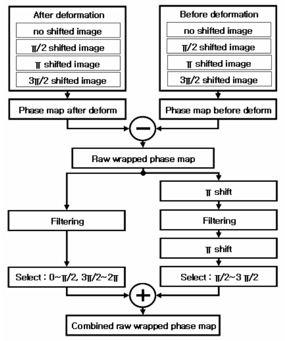


Fig. 3 Signal flowchart to obtain wrapped phase information

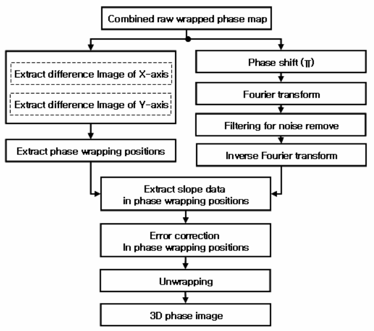
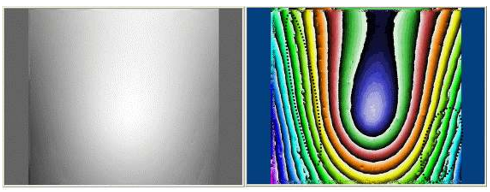
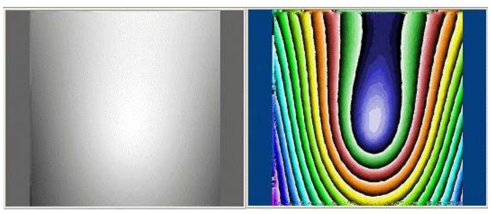


Fig. 4 Signal flowchart for error correction in phase wrapping positions



(a) 3D image using conventional unwrapping algorithm



(b) 3D image using developed unwrapping algorithm

Fig. 5 Measured 3D phase images and their 16 pseudo-colored image.

Fig. 5(a) and Fig. 5(b) show the experimented 3D phase images and their 16 pseudo-colored images by using the conventional unwrapping algorithm and the developed algorithm, respectively. Here, the object is a steel plate which is deformed in the out-of-plane direction. We can see some phase errors in the dot-circle area from the conventional unwrapping results as shown in Fig. 5(a), but the developed unwrapping algorithm provided better phase data as shown in Fig. 5(b).

Fig. 6 shows a line profile of the X-axis direction in Fig. 5. Fig. 6(a) and Fig. 6(b) are the results from the conventional and developed phase unwrapping algorithms, respectively. From the experimental results, our developed algorithm provide improved phase data as shown in Fig. 6(b).

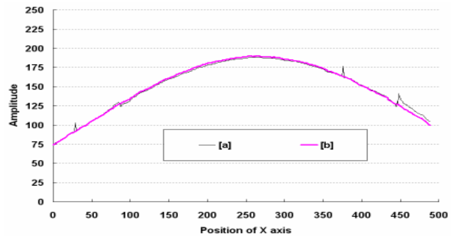


Fig. 6 Comparison of the phase unwrapping results between conventional (a) and developed (b) phase unwrapping algorithm.

4. Conclusion

A digital speckle pattern interferometer was developed to measure micro deformation of an object. A Л-shift filter with a low-pass-filter in frequency domain was designed to remove impulse pattern noises that exist nearby wrapping positions. From the experimental results, this filter provided improved 3D phase information. We confirmed that the DSPI system is a valuable tool for measuring the micro deformation in the industries.

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