Signal Processing Technique for Measuring a Micro Deformed Surface Shape by Using a Laser Interferometer

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1. Introduction

Nondestructive inspection of structural materials is becoming increasingly important to assure the safety level in the present industries. In recent years, nondestructive measuring techniques using an optical interferometer have emerged as a valuable tool for many industrial applications by virtue of the development of electronic technologies. The optical interferometer based non-contact inspection method is a full-field precise measurement technique and a fast measuring technique [1].

Recently, a digital speckle pattern interferometer has been 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 area data by using phase-analyzing techniques. The acquired phase image from a laser interferometer is wrapped when the deformation phase is larger than the wavelength of a laser beam. So, the 3D surface information should be extracted from the wrapped phase image. In the wrapped phase image, much of the impulse pattern noises are induced because of the laser speckle itself. Also, discontinuities could exist at the wrapping positions. These noises can cause non-ignorable errors during the extraction of phase information from wrapped phase data.

In this paper, a signal processing technique is developed to measure the micro surface deformed shape by using a laser interferometer. A simple and robust filter is designed to reduce the noise effects in a wrapped phase map data. The filter improves the extracting efficiency of the phase information, especially at the wrapping positions. To extract the 3D phase shape from the wrapped phase map, a DCT(discrete-cosine-transform) based least squares phase unwrapping technique is applied. This technique was robust for noise and it supplied improved phase information with high speed.

2. Signal processing algorithm to extract the phase data using a laser interferometer

A center line-profile of a measured phase map for a convex object by using a laser interferometer with a 4-bucket algorithm is shown in Fig. 1 [2]. In here, the phase data from 0 to 2π is normalized to the digital value of from 0 to 255. As shown in Fig. 1, much of the speckle noise is observed. In here, we can see that the noise data has wideband frequency components but the signal data usually has lower frequency components. Also, various types of discontinuities are observed at the wrapping positions. These discontinuities can cause relatively large errors during extraction of unwrapped phase data from a wrapped phase map.

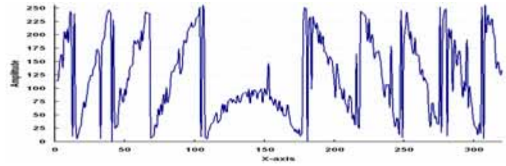
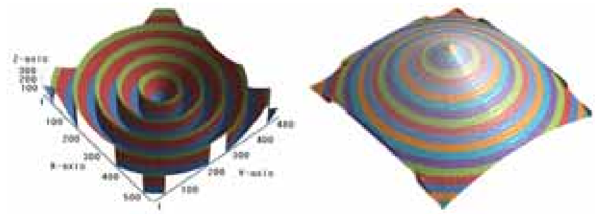


Fig. 1 Measured one-line phase map for a convex object

The π-shifting filter combined with a median filter or a smoothing filer is widely used to reduce the speckle noise. This conventional filter has improved the signal-to-noise of the phase data by reducing the noise effects.



(a) (b)

Fig. 2 Simulated phase map without noise (a) and its unwrapped phase image (b)

In this paper, we designed a simple and robust π-shifting filter which is combined with a low pass filter operated in the frequency domain. To observe the performance of the designed filter, we generated a phase map by computer simulating a convex object as shown in Fig. 2(a). The unwrapped phase image as shown in Fig. 2(b) is acquired by applying a DCT based least-squares phase unwrapping algorithm. The signal processing procedure is as follows. First, a partially differenced image of $\rho_{i,j}$ is acquired according to equation (1).

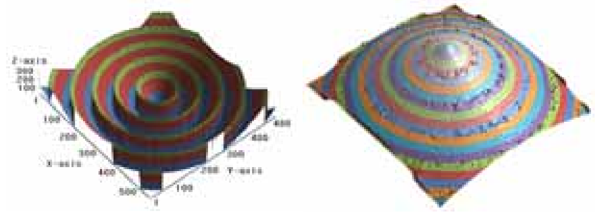
$$\rho_{i,j} = (\phi_{i+1,j} - 2\phi_{1,j} + \phi_{i-1,j}) + (\phi_{i,j+1} - 2\phi_{1,j} + \phi_{i,j-1}) \quad (1)$$

Where $\phi_{i,j}$ is the intensity at the position of (i, j) of a phase map. The image sizes of the X-axis and Y-axis are N(=512) and M(=512), respectively. Then a two-dimensional discrete cosine transform is computed for the $\rho_{i,j}$ image and its components are replaced according to equation (2).

$$\tilde{\phi}_{i,j} = \frac{\tilde{\rho}_{i,j}}{2\cos(\pi i / M) + 2\cos(\pi j / N) - 4} \quad (2)$$

And then, an unwrapped phase data is extracted by acquiring the inverse cosine transform of $\tilde{\phi}_{i,j}$ image [3].

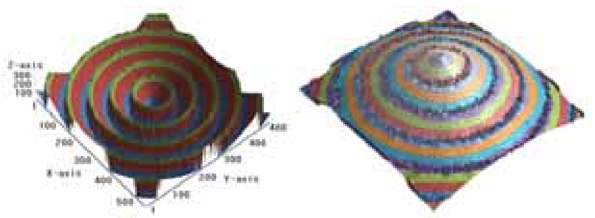
The generated phase map with noise of 5 % and its unwrapped phase image are shown in Fig. 3 (a) and Fig. 3 (b), respectively. The noise is generated within 10 % at the wrapping positions and its value is a randomly normalized value from 0 to 255.



(a) (b)

Fig. 3 Simulated phase map with noise of 5 % (a) and its unwrapped phase image (b)

The generated phase map with noise of 30 % and its unwrapped phase image are shown in Fig. 4 (a) and Fig. 4 (b), respectively. Much of then unwrapping errors are observed around the wrapping positions of the unwrapped phase image.

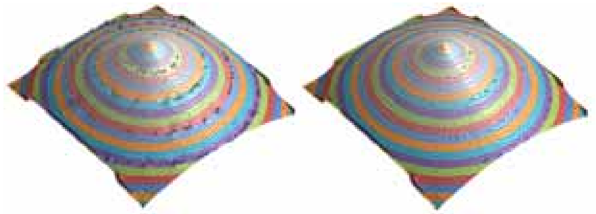


(a) (b)

Fig. 4 Simulated phase map with noise of 30% (a) and its unwrapped phase image (b)

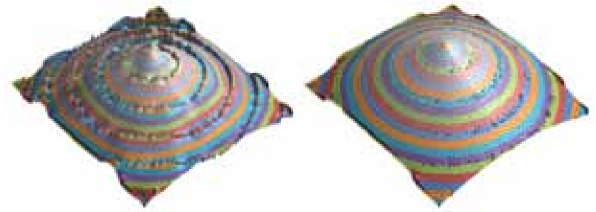
For the wrapped phase map of Fig. 2(a), the unwrapped phase image by using the conventional π-shifting filter using a median filter with a window size of 7x7 pixels and a smoothing filter with a window size of 7x7 pixels is shown in Fig. 5(a). Fig. 5(b) is the unwrapped phase image by using the designed π-shifting filter combined with a low pass filter in the frequency domain whose window type is a circle and its radius is 8 pixels.

Fig. 6(a) is the unwrapped phase image from the Fig. 4(a) by using the conventional π-shifting filter and Fig. 6(b) is the unwrapped phase image by using the designed filter in this paper.



(a) (b)

Fig. 5 Unwrapped phase image for the phase amp with noise of 5% by using the π-shifting filters of a median filter and a smoothing filter (a) and by using the π-shifting filter with frequency domain low pass filter (b), respectively.



(a) (b)

Fig. 6 Unwrapped phase image for the phase amp with noise of 30% by using the π-shifting filters of a median filter and a smoothing filter (a) and by using the π-shifting filter with frequency domain low pass filter (b), respectively.

3. Conclusion

A signal processing technique was developed to measure a micro deformed surface shape of an object. An improved phase data was acquired by using the designed π-shifting filter combined with a low-pass-filter operated in the frequency domain. This filter is robust for the impulse pattern noise and provided an advanced result with high speed. Also, the DCT based least-squares phase unwrapping algorithm improved the quality of the extracted phase data. Through the experiment, we confirmed that the designed signal processing technique is a valuable for a laser interferometer.

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