IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

Volume 13, Issue 5, May 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.317

9940 572 462 | 6381 907 438 | ijareeie@gmail.com | www.ijareeie.com

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 5, May 2024||

|DOI:10.15662/IJAREEIE.2024.1305066|

Deformation Assessment through Speckle Interferometry with Fringe Analysis Method

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ABSTRACT: The fringe analysis method is proposed in this paper, utilizing a simple optical system where a plane wave serves as the reference beam in the speckle interferometer. When the optical system is employed in fringe analysis, the deformation information and the bias components of the speckle patterns are distinctly separated in the frequency domain. As a result, the deformation information can be easily extracted through a Fourier transform, yielding a pair of real and imaginary components about the information. The specklegram is then computed and the phase map is derived from the specklegram. It was confirmed through experimental results that the resolution power of this measurement method exceeds 1/261 of the wavelength of the light source of the optical system.

I.INTRODUCTION

The experiment involves assessing deformation using speckle interferometry with the fringe analysis method. Speckle interferometry utilizes laser light to create a speckle pattern on a surface, and by analyzing changes in this pattern over time, deformations in the object can be measured. The fringe analysis method further enhances precision by examining interference fringes formed during the process. This approach provides valuable insights into structural changes, making it a robust technique for deformation assessment in various materials and surfaces. Two methods of analysis for deformation measurements in speckle fringe analysis are known. The first method involves the direct analysis of speckle patterns, known as the 'difference of phase method'. This analysis method's approach is generally similar to that of digital holography technology. The second method involves the analysis of the specklegram produced by speckle images ahead and following deformation, known as the 'phase of difference method'. Generally, the former method cannot achieve high-resolution fringe analysis due to the complex signal by speckle noise treated in the fringe analysis.

A good resolution fringe study can be achieved by enhanced filtering technology for the fringe analysis study in the method. However, the phase of the difference method, which is the deformation analysis method based on only two speckle patterns, was not often used in ordinary speckle analysis because two speckle patterns can produce only one specklegram; thus, fringe investigation in good resolution power cannot be performed using only one specklegram. A novel method is proposed in this paper, which combines the difference of phase method with the phase of the difference method in the fringe analysis process to achieve higher resolution deformation measurement using only two speckle patterns. When the new optical system is employed, the speckle patterns that are identical to images in off-axis digital holography can be captured, as demonstrated in the previous discussion. Therefore, the bias component can be smoothly removed by the operation based on the difference of phase method. The phase map can be efficiently determined from one specklegram by removing the bias component of the speckle patterns in a manner similar to digital holography technology. However, although the same operation used in digital holography technology is performed in the frequency domain, the proposed deformation measurement method is clearly different from digital holography processing. The proposed method is a technology for high-resolution deformation measurement by speckle interferometry. It differs from digital holography technologies in that it employs the combined fringe analysis method with the difference of phase method and the phase of difference method, using enhanced filtering technologies to perform high-resolution speckle interferometry. The main distinction is that the proposed method is a high-resolution measurement method for the deformation of an object with rough surfaces, giving it a different purpose than digital holography technologies.

The square operation of the difference between the intensities of the speckle patterns is usually employed for producing a specklegram in speckle interferometry. The assumed intensities of the speckle patterns before and after the deformation (S0, S1) are given, in the same manner as the intensity distribution model shown in Equation (2).

$$I0(x,y) = a0(x,y) + b0(x,y)\cos\emptyset0(x,y) \quad \ldots (1)$$

$$I0(x,y) = a0(x,y) + b0(x,y)\cos(\emptyset0(x,y) + \Delta0(x,y)) \quad \ldots (2)$$

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Where, $a0(x,y), b0(x,y), \emptyset 0(x,y) + \Delta 0(x,y)$ are the bias, the amplitude, the random phase distribution including spatial information and the phase change value due to the deformation respectively. As shown below, the specklegram, Isg(x,y), is determined by calculating the square of the difference between Equations (1) and (2):

$Isg(x,y) = ((Isp1(x,y) - Isp2(x,y))2$ ….(3)

$=b0^2(x,y)+ b0^2(x,y)/2 \times Cos2\emptyset 0(x,y)+ b0^2(x,y)/2 \times cos2\emptyset 0(x,y)+ \Delta 0(x,y)) - b0^2(x,y)^2/2 \times cos2\emptyset 0(x,y) + \Delta 0(x,y)) - b0(x,y)^2 \cos\Delta 0(x,y)$ ….(4)

In Equation (4), all terms except the first and fifth terms are composed of random components. Furthermore, because the first term is a bias, it can be deduced that the main deformation signal is present in the fifth term of Equation (4). Therefore, the unknown value term as a bias can be eliminated by extracting only the fifth term from Equation (4). The fringe analysis process, utilizing only two speckle patterns before and after deformation, can then be accomplished with filtering technologies.

II.PROPOSED METHOD

The calculating process of the phase map When the signal components are extracted by a 2-D bandpass filter, the fringe images are given. The phase difference of the fringe images is $\pi/2$ rad. Therefore, the total phase map is determined by using the arctangent function. Figure 8(a) shows the result. Figure 8(b) displays an unwrapped phase map resulting from the unwrapping operation. The standard deviation of the error between the measured phase map and the practical deformation caused by a piezo actuator is 0.048 rad. The measurement accuracy is nearly 1/261 of a wavelength, as the optical system is a double-path system optically. The proposed method achieves a very high-resolution measurement. Figure 9 displays the wrapped phase map based on the difference of phase method using the value in Equation (9). The phase map obtained by the difference of phase method contains considerable noise. The analysis based on the difference of phase method, commonly used in digital holography, is not advantageous in speckle interferometry. Special fringe analysis based on enhanced filtering technologies should be employed in speckle interferometry.

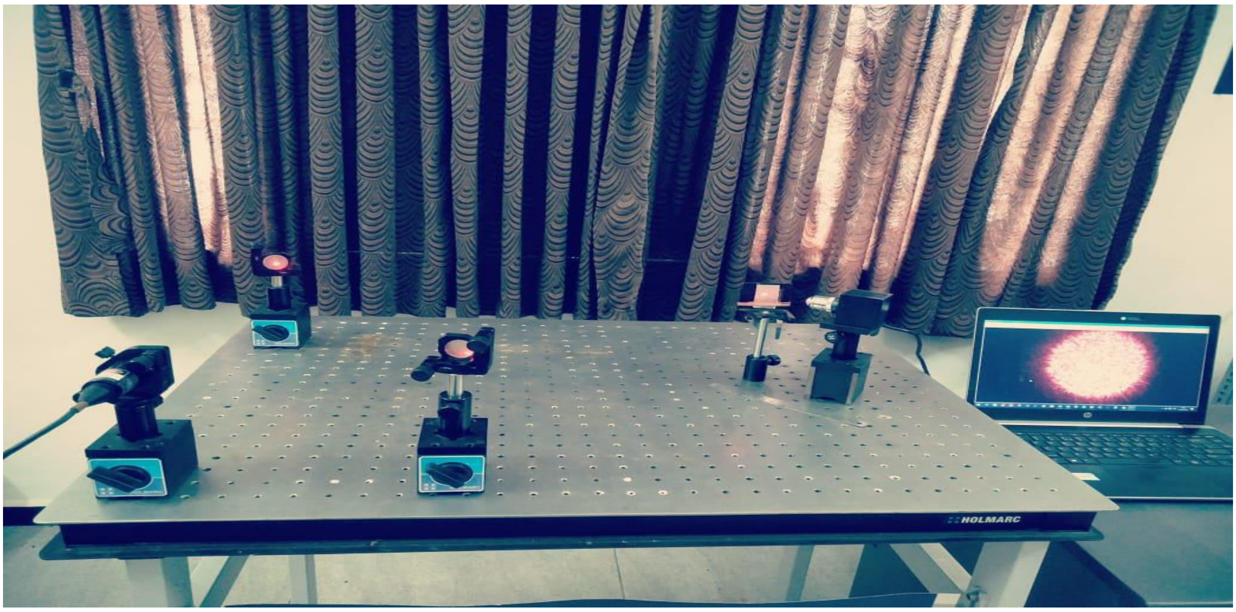

Figure.1. Experimental Setup

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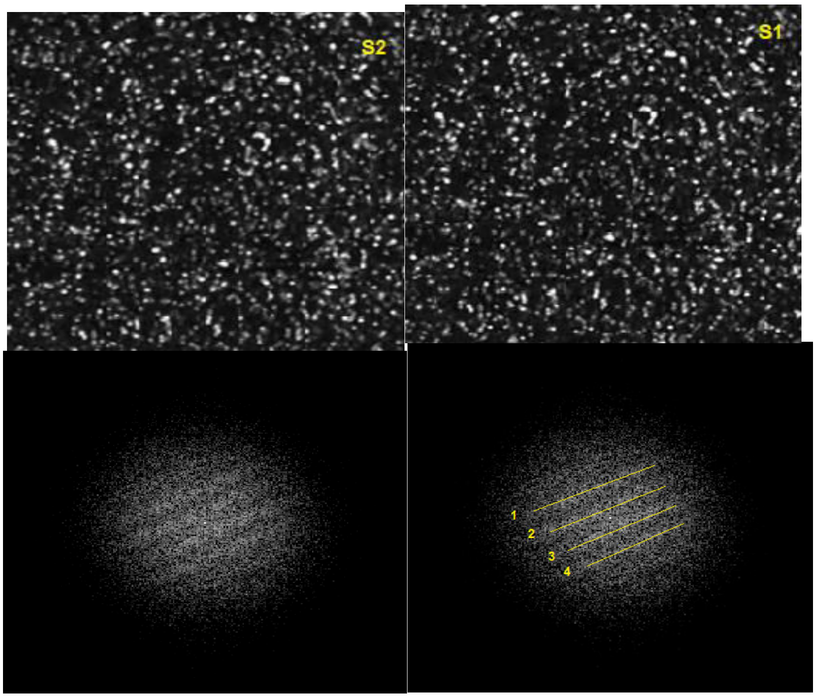

Figure.2. Simulation Output

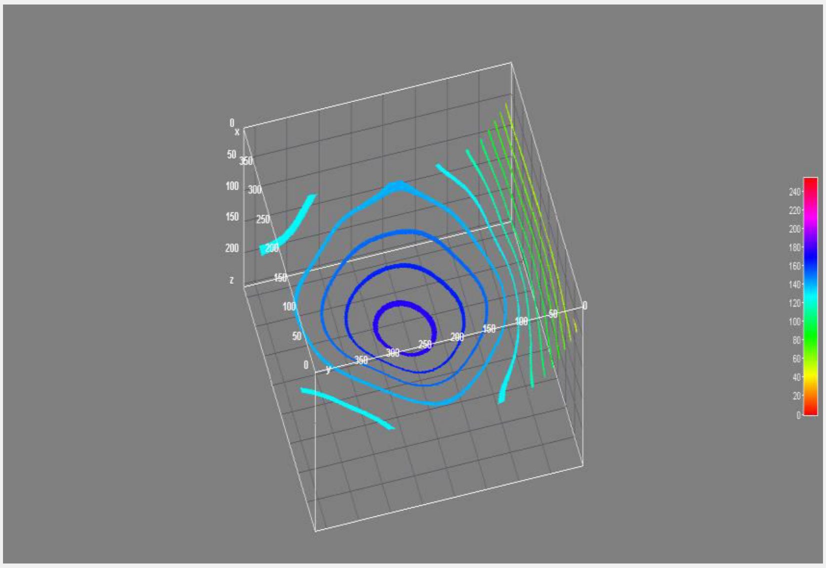

Figure.3.3D Fringe View

A method was discussed that utilizes a new feature of the speckle pattern, specifically fringe analysis based on a Fourier transform. A method was proposed that can remove the bias component of the specklegram by using filtering technologies in the frequency domain. The optical system for utilizing this new feature of the speckle interferometer was configured. Consequently, a high-resolution analysis method was realized. Experiments demonstrated that the proposed speckle interferometry can analyze a measured object with a monotone phase distribution or a concave phase distribution by using only two speckle patterns before and after the deformation of the object.

III.CONCLUSION

The discussion centered on a method utilizing a novel aspect of the speckle pattern, specifically, fringe analysis based on a Fourier transform. A technique for eliminating the bias component of the specklegram through the application of

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filtering technologies in the frequency domain was introduced. The optical system designed to leverage this new feature of the speckle interferometer was established. Consequently, the realization of a high-resolution analysis method was achieved.

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