International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-3, February 2013

Digital Image Processing Technique in Laser Speckle Pattern Interferometer for Phase Evaluation

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Abstract: ***In this paper, Electronic laser speckle pattern technique has been adopted to measure small deformation/displacement of a specimen. A low cost Laser Speckle Interferometer has been designed with minor modification of Michelson Interferometer. Laser speckle images are recorded before the deformation (reference image) and then after deformation. By simple subtraction of the digital speckle images, a fringe pattern obtained using image processing technique. It gives information about the displacement by means of its phase evaluation.***

Keywords: ***Laser speckle, image Subtraction, displacement/deformation.***

I. INTRODUCTION

A. Speckle interferometry has always been paid much attention because of its many advantages, such as non-contact, high-accuracy measurements [1] in metrology. A speckle pattern is generated when an object with a rough surface is illuminated with a highly coherent source of light such as laser. In the past, speckles were viewed as a disturbance to be suppressed or eliminated. However, measurement based on the laser speckle phenomenon has now become an important subject of optical metrology for full-field NDE (Non destructive Evaluation).The speckle techniques can be classified into three broad categories: speckle photography, speckle interferometry and speckle shear interferometry. Speckle photography [2] includes the methods where positional changes of the speckle are monitored. Speckle interferometry [3] on the other hand includes methods that are based on the measurement of phase changes. If, instead of the phase change, we measure its gradient, the method falls into the category of speckle shear interferometry or shearography [4]. Full-field laser NDE techniques are based on the optical effect of interferometry. If a rough surface is illuminated by laser light, the light will be scattered back from every illuminated object point shown in Fig.1. If the object is viewed by an eye or the camera, the object surface seems to be covered with bright and dark spots, which are called speckle. These speckles result from the path differences of the light emitted by the laser and reflected to the camera via different surface points. When coherent light is incident on an optically rough surface, with height variations greater than the wavelength of the light and is scattered from it, a pattern consisting of dark and bright spots (speckles) is seen in Fig.2. The scattered waves interfere and form an interference pattern. This phenomenon is called the speckle effect. In white light illumination, this speckle effect is difficult to observe because of lack of coherence. The speckle pattern is characterized by a random intensity and phase distribution. It is fundamentally a statistical process [5]. The intensity I is distributed according to the probability density function of a fully developed, polarized speckle field as follows:

$$P(I) = 1/\langle I\rangle \exp\{- I/\langle I\rangle\}, \quad I \geq 0 \qquad \ldots\ldots\ldots.(1)$$

where I is the mean intensity value. The intensity follows a negative exponential distribution given in Fig.3.

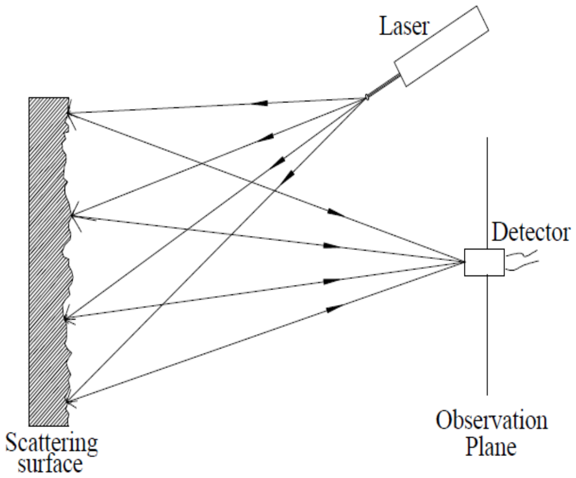

Fig.1 Basics for Speckle image formation

Manuscript published on 28 February 2013.
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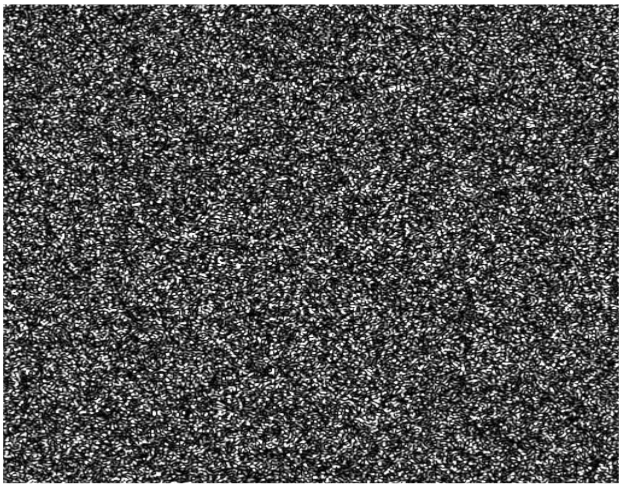

Fig.2 Speckle pattern

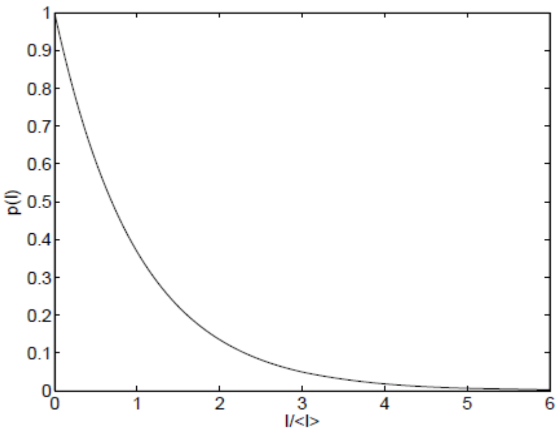

Fig.3 Intensity distribution of polarized speckle

If the statistical properties of the speckle pattern are determined by the size of the illuminated spot, the pattern is called objective. Instead if the statistical properties of the speckle pattern are determined by the aperture of the imaging system, the pattern is called subjective. For the case of a rectangular aperture the in-plane speckle width is defined as:

$$\sigma_{x,y} = \lambda L/D \qquad \text{………... (2)}$$

where λ is the wavelength of the light, L is the distance between the aperture and the detector and D is the width of the rectangular aperture. The speckle length [6] is defined as:

$$\sigma_z = 7.31\lambda\{L/D\}2 \qquad \text{…...…… (3)}$$

This means that the speckles have the shape of a cigar, since they have a larger size in the z-direction than in the x- and y-direction, unless for very large numerical apertures. The basic importance of the speckle size in metrology lies in the fact that it has to be adjusted to the resolution of the detector not to introduce systematic errors into the analysis.

II. EXPERIMENTAL SETUP

Digital speckle interferometry measures the displacement based on the principle of Michelson Interferometer [7] as shown in Fig.4. Instead of mirrors M1and M2 we use acrylic boards which are having optical roughness. The light source is a 5-mW laser diode at the wavelength λ=680 nm.

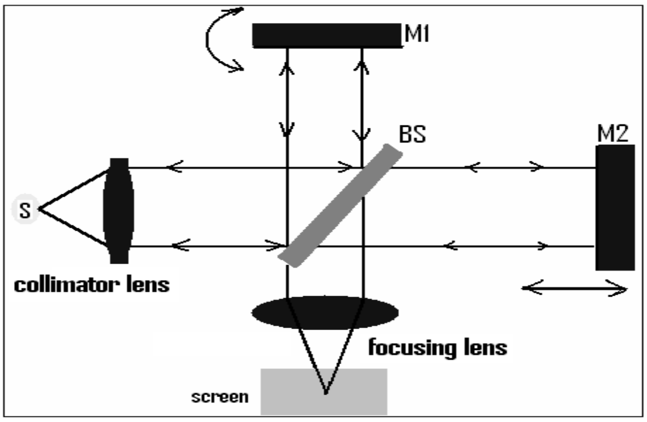

Fig.4 Michelson interferometer

A lens is used to increase the laser divergence and the scattering surfaces are acrylic small boards. The scattering angle is typically wide, such surfaces do not need to be exactly aligned and a polished glass plate with partial metal coating on one face as a beam splitter. One of the acrylic pad is deformed by pushing a mechanical tip (micrometer) on its rear side and it should not exceed a few microns for avoid many fringes. The beam splitter split the laser beam into two beams, each of which falls on different surfaces [8]. For these conditions there are two overlapping images of the diffusing surfaces on the screen, each being a speckle field. Arm lengths adjusted such a way that the optical path difference is within the coherence length of the source, equalizing the distance between the diffusers and the beam splitter. The two fields interfere, although the resulting intensity distribution still appears as a speckle pattern due to the random nature of the interfering fields and thus no fringe is visible. Because of the double pass in reflection, the actual path difference is:

$$(x,y)=2\Delta(x,y)\lambda/2 \qquad \text{…………(4)}$$

The condition of phase opposition is that path difference is an odd multiple of λ /2, or equivalently the displacement is $\Delta(x,y)= (\lambda/4)(2N+1)$, where N is an integer. Conversely, the intensity of the speckle grain is unchanged when path difference is an even multiple of λ /2, so that the displacement is:

$$\Delta(x,y)= (\lambda/2)\, N \qquad \text{……….(5)}$$

The speckle correlation is carried out by storing an image while the object is in its initial state, and subtracting the subsequent frame from this stored frame, displaying the difference on the monitor.

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Fig.5 Speckle pattern before (A) and after (B) displacement

When the object is subjected to some loading or excitation, the correlated areas appear black while the uncorrelated areas would be bright, resulting in a fringe pattern. The fringes represent contours of constant displacement of the object points.

The theory behind the fringe formation is as follows [9]. Let the O_1 and O_2 represent the undeformed and deformed object waves, which are written as:

$O_1(x,y) = |O_1(x,y)| \exp[-i\varphi(x,y)]$ ...(6)

$O_2(x,y) = |O_2(x,y)| \exp[-i\, \varphi(x,y) + \delta\,]$ ...(7)

where δ is the phase change due to displacement or deformation of the object. The intensity due to superposition of these two waves is:

$I(x,y) = |O_1(x,y) + O_2(x,y)|_2$

$= O_1O_1^* + O_2O_2^* + O_1O_2^* + O_1^*\, O_2$

$= I_1 + I_2 + 2I_1I_2 \cos\delta$ ...(8)

where, I_1 and I_2 are the intensities of O_1 & O_2.

The Phase Difference δ is given by:

$\delta = (K_2 - K_1).L$ ….(9)

where K_2 is the observation vector, K_1 is the illumination vector and L is the displacement vector. Thus the valuation of the phase δ is gives the displacement [10].

III. RESULT

Electronic Speckle Pattern Interferometry is based on the coherent addition of the scattered light from the specimen surface and a reference surface beam [11-14] is a very good tool for optical metrology.

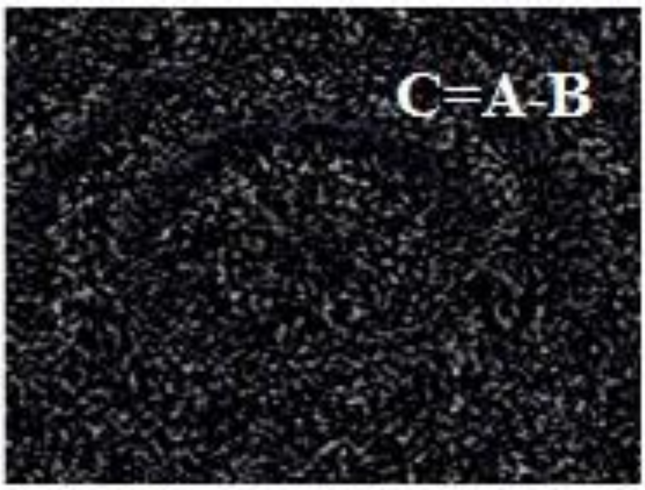

Fig.6 Speckles (Before & after) with Subtracted fringe Pattern

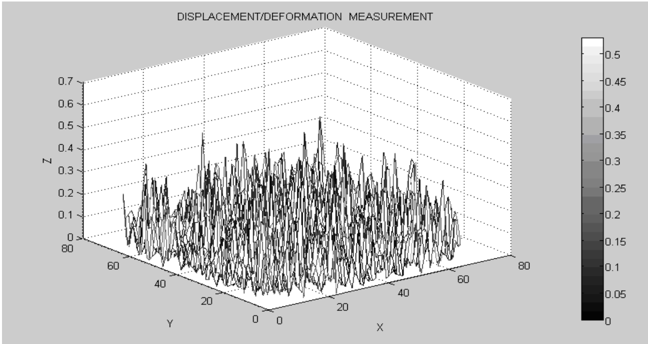

Fig.7 Deformation measurement (Peak value)

IV. CONCLUSION

This paper shows recent developments and applications of digital image processing technique in optical metrology. A non- contact and low cost device designed based on the principle of Michelson Interferometer. The Electronic Speckle Pattern Interferometry based method described here can be used to accurately and precisely measure the displacement value 0.5micrometer, which compares quite favorably with other conventional contact methods of deformation/displacement measuring devices like strain gauge and LVDT (Linear Variable Differential Transformer).

ACKNOWLEDGEMENT

The authors would like to thank management of Kumaraguru College of technology for the continuous support to this work.

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