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Analysis of Lau interferometric fringe for measurement of focal length by using wavelet filtering techniques

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ABSTRACT

New filtering scheme is investigated and implemented on Lau interferometric fringes to enhance the signal-to-noise ratio (SNR) in the Lau interferograms. Towards this, the applicability of Haar, Daubechies and Symlet wavelet based filtering schemes have been tested. Of these schemes, the Symlet based filtering scheme gives the best results in terms of improved signal to noise ratio and speckle index. This scheme is then used to analyse Lau interferograms recorded in the experimental arrangement for focal length measurement. The processed interferograms yield improved accuracy and precision of measurement.

1. Introduction

Lau phase Interferometry has been used for diverse applications such as in area of image processing, optical array generation, optical metrology, etc. Lau effect has been used to implement several important operations in the field of optical image processing.

Colautti et al. [1] proposed a Lau effect based method for carrying out spatial filtering operations on certain kind of object transparency. A related approach to spatial filtering based grating interferometers using Lau effect was proposed by Leith and Hershey [2]. A spatially incoherent technique for decoding theta-modulated information based on Lau effect was proposed by Ojeda et al. [3]. The use of Lau interferometer for determination of the focal length of collimating lens [4], profiling of reflecting surface [5] and in vibration analysis [6] has also been demonstrated. Among various advantages offered by the Lau based interferometers, is the fact that they use inexpensive components. Since the technique uses the incoherent light, the coherent noise is minimized. In the present communication, we test the applicability of the wavelet based filtering techniques to de-noise the recorded Lau interferogram and use the technique for measurement of focal length.

Several image de-noising algorithm have been proposed in the literature. These algorithms have been tested on variety of images such as normal pictures, moiré based fringes, digital speckle based fringes, tomographic images etc. Recently, in all these formats, there has been incorporation of wavelet filtering techniques because of inherent advantages in its use. Heng Liu [7] has proposed a Phase shifting interferometry combined with wavelet-based image processing techniques to extract precise phase information for applications of moire′ interferometry. Tay [8] proposed a method based on temporal wavelet analysis to retrieve transient velocity, displacement, and surface contour on a continuously deforming object. Kumar et al. [9,10] have proposed wavelet filtering scheme for speckle noise reduction in digital speckle pattern interferometry (DSPI). Barj et al. [11] presented a stationary wavelet transform (SWT) method for speckle noise reduction in DSPI fringes. Mio et al. [12] described the analysis of phase distortion in phase-shifted fringe projection method. Quan et al. [13] proposed a novel temporal phase analysis technique based on wavelet transform when shearography is applied to measure a continuously deforming object. Chia-Ming Liu et al. [14,15] have reported the use of wavelet transform to remove the noise embedded in moiré interferogram recorded using digital AFM moiré method. Gdeisat et al. [16] and Abdulbasit et al. [17] proposed the spatial fringe pattern demodulation using two-dimensional continuous wavelet transform. Li et al. [18] presented a wavelet transform (WT) analysis to obtain the deformation phases from the fringes with non-uniform carrier frequency, which may appear in the pattern of varied-periodic fringes generated in displacement measurement. Singh et al. [19] applied wavelet filtering techniques to Lau interferometric fringes for measurement of small tilt angles.

Looking into the success of wavelet based methods in DSPI, we investigate the applicability of the preprocessing schemes and wavelet filters in analysing the Lau interferometric fringes. The processing schemes and the wavelet filtering scheme is then applied to the interferometric fringe data obtained through Lau based focal measuring set-up. It has been observed that improved

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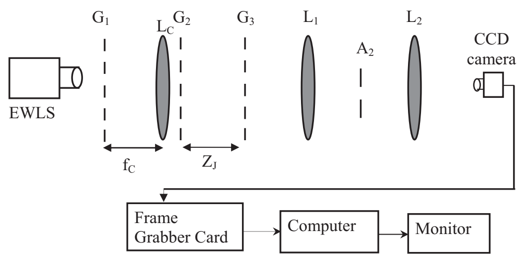

Fig. 1. Schematic of the experimental arrangement for focal length measurement using Lau interferometry.

measurement accuracy and the precision are obtained using the above technique.

2. Theory

Wavelet transform is capable of providing the time and frequency information simultaneously, hence giving a time–frequency representation of the signal. Wavelet transform, due to its excellent localization property, has rapidly become an indispensable signal and image processing tool for a variety of applications, including compression and denoising [20]. The wavelet transform itself offers great design flexibility. Basis selection, spatial-frequency tiling, and various wavelet threshold strategies can be optimized for best adaptation to a processing application, data characteristics or for the applications of interest. Wavelets have emerged as a powerful tool for image filtering. Filtering methods based on wavelet transform provide significant noise reduction while maintaining the sharpness feature of the image as compared to Fourier transform.

The Lau effect is an interference phenomenon observed at infinity when light from a spatially and temporally incoherent source passes through two diffraction gratings separated by a distance of $Z = md^2/\lambda$, where m, d, and λ represent an integer, the period of the grating, and average wavelength of light used, respectively. Recently, the Lau effect has been used for measurement of focal length has been reported by us [4]. The accuracy of the technique is determined mainly by the accuracy involved in the measurement of the inclination angle of the recorded moiré fringes. Because of the presence of several parameters degrading the image quality and the noise present, the accurate determination of inclination angles is difficult to make. The attempt has been made to incorporate wavelet filtering techniques in the interferogram analysis, so as to improve the accuracy and precision of measurement.

3. Experimental arrangement

Fig. 1 shows a schematic diagram of the experimental arrangement for focal length measurement using Lau interferometry. It consists of an incoherent white light source and a set of three identical coarse gratings G_1, G_2 and G_3. The light from white light halogen lamp is incident on the grating G_1. Diverging wavefronts from the grating G_1 are incident on the collimating lens. Openings of the grating G_1 can be thought of as an array of point sources placed at the front focal plane of collimating lens. Plane wavefronts from collimating lens illuminate grating G_2, forming self images at a plane separated by a distance $Z = nd^2/\lambda$. Defocusing of collimating lens results in formation of magnified self-image. An identical grating G_3 is placed such that its grating lines are inclined at an angle θ with respect to grating G_2. The self-image of grating G_2 is superimposed with G_3 resulting in generation of moiré fringes. Defocusing of optical beam magnifies/de-magnifies the self-image, which causes moiré fringes to rotate through an angle Φ. The experiment was performed by defocusing the collimating lens through

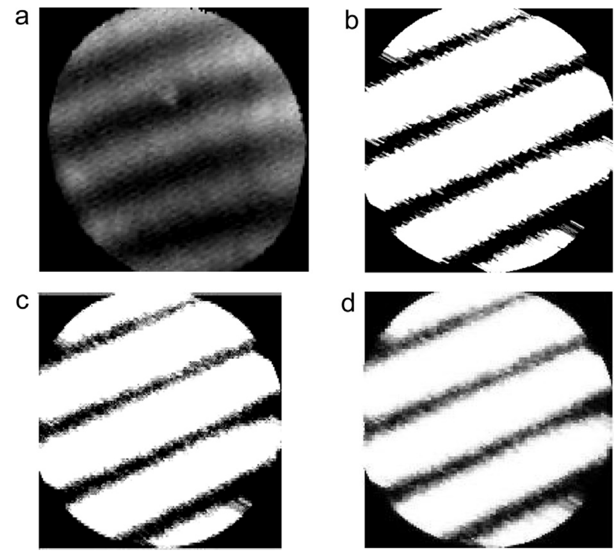

Fig. 2. (a) Image recorded directly through the CCD camera as per experimental set-up in Fig. 1. (b) Image after incorporation of wavelet filtering scheme based on Haar wavelet. (c) Image after incorporation of wavelet filtering scheme based on Daubechies wavelet. (d) Image after incorporation of wavelet filtering scheme based on Symlet wavelet.

distances x_1 and x_2. By taking two sets of readings (Φ_1, Φ_2) corresponding to defocusing distances x_1 and x_2, following expression can be deduced for the focal length of collimating lens [4].

$$f = \left[\frac{Z_J}{2} \left(\frac{1}{x_1} - \frac{1}{x_2} \right)^{-1} \left(\frac{1}{\tan \Phi_1} - \frac{1}{\tan \Phi_2} \right) \cot(\theta/2) \right]^{1/2} \quad (1)$$

The results of the investigation are recorded directly via CCD camera interfaced with the computer using a frame grabber card. Fig. 2(a) shows the image recorded directly through the CCD camera. It is evident from the figure that the recorded interferogram is noisy and also the contrast and brightness of the image is poor.

4. Image denoising algorithm

The directly recorded interferogram is shown in Fig. 2(a). It is quite evident from the figure that the visibility and sharpness of fringes is poor. A preprocessing scheme has been undertaken to improve image quality of the Lau interferogram obtained in the experimental arrangement as shown in Fig. 1. It consists of following steps:

(1) In the first step the brightness and image contrast of Lau fringes is improved by wavelet toolbox in the Matlab environment.
(2) The resulting interferogram still has salt and pepper noise. Salt and pepper noise is a form of noise typically seen on white light images. It represents itself as randomly occurring white and black pixels. Usual and effective noise reduction method for this type of noise involves the usage of median filter. It is edge-preserving nature makes it useful in cases where edge blurring is undesirable. It is particularly useful to reduce speckle noise and salt and pepper noise.
(3) The next step in denoising the interferograms involves the use of soft and hard thresholding. This procedure involves following steps:
    (a) In the first step, discrete wavelet transform (DWT) of each row is calculated.
    (b) Only the values of DWT above a certain threshold are retained.