Optik 125 (2014) 4168–4171

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Multi-parameter measuring method of image intensifier based on Fourier transform phase measurement

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ARTICLE INFO

Article history:
Received 18 June 2013
Accepted 27 January 2014

Keywords:
Image intensifier
Fourier transform phase measurement
Pillow-shaped distortion
Snake-shaped distortion
Shear distortion

ABSTRACT

A new quality parameter measuring method of image intensifier based on Fourier transform phase measurement is proposed. A standard sinusoidal fringe pattern is projected into the measuring system by spatial light modulator and the corresponding reference pattern and deformed pattern are captured by CCD. The Fourier transform and inverse Fourier transform are applied in order to extract the phase distribution of deformed pattern. The magnification, pillow-shaped distortion, barrel-shaped distortion, snake-shaped distortion and shear distortion of image intensifier are obtained at the same time. Experiment has proved its feasibility with real-time performance and without manual intervention.

1. Introduction

Image intensifier is a kind of low-level light detector and it is mostly used in night vision device [1]. Generally, the quality parameters of image intensifier contain the magnification, pillow-shaped distortion, barrel-shaped distortion, snake-shaped distortion and shear distortion. It is an important condition that the quality parameters of image intensifier are detected quickly to insure the image intensifier is applied effectively. Linders Peter W has measured the relevant quality parameters of X-ray image intensifier tube [2], Wang Xiaohui and Ning, Ruola have corrected the image intensifier distortion [3], but they did not catch the traditional quality parameters of image intensifier. McRobbie D W and Nieto-Camero, J J assessed the property of image intensifier by its modulation transfer function [4], but they did not obtain the parameters of image intensifier. Cuelenaere A J applied the principle of optical lens to research the parameters of image intensifier [5], but it too complex and time-consuming. On the whole, the traditional quality parameter measurement of image intensifier is complex, defective and inefficient. The Fourier transform has been applied in spectral analysis [6], signal analysis [7], picture processing [8], 3D object measurement [9–13] and other aspects. So a new quality parameter measuring method of image intensifier based on Fourier transform phase measurement is proposed. A standard sinusoidal fringe pattern is projected into the measuring system by spatial light modulator and the corresponding deformed pattern is captured by CCD. The quality parameters of image intensifier are calculated after the relevant data are extracted from the deformed pattern by applying Fourier transform and inverse Fourier transform. The proposed method can obtain the multi-parameters of image intensifier at the same time and it avoids the manual intervention. So the proposed method is real-time and accurate.

2. Structure and working principle of image intensifier

The schematic of image intensifier system is shown in Fig. 1. It consists of objective lens, image intensifier and eyepiece [14]. The image intensifier is the primary component and it consists of photocathode, electron lens and phosphor screen. Many electrons are gushing from the photocathode when the light is captured by the image intensifier. Then theses electrons are assembled to the phosphor screen by electron lens and the image is shown.

Generally, some distortions will happen when the image is shown by image intensifier. These distortions are shown in Figs. 2 and 3.

3. Parameter measuring of image intensifier based on Fourier transform phase measurement

A standard sinusoidal fringe pattern is projected into the measuring system by spatial light modulator before the image

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http://dx.doi.org/10.1016/j.ijleo.2014.01.048

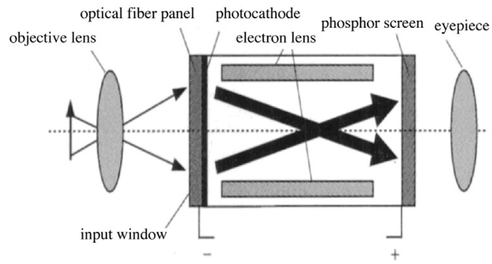
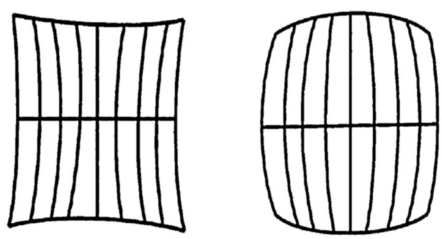


Fig. 1. Schematic of image intensifier system.



(a) pillow-shaped distortion (b) barrel-shaped distortion

Fig. 2. Pillow-shaped distortion and barrel-shaped distortion.

intensifier is placed in and the corresponding reference pattern is captured by CCD. The reference pattern can be expressed as [15,16]

$$g(x,y) = a + b\cos\left[\frac{2\pi x}{T} + \varphi(x,y)\right] \tag{1}$$

where a refers to the background intensity, b refers to the contrast, T refers to the period, $\varphi(x,y)$ refers to the phase distribution.

The standard sinusoidal fringe pattern is projected into the measuring system again after the image intensifier is placed in and the corresponding deformed pattern is captured by CCD. The deformed pattern can be expressed as

$$g_a(x,y) = a_a(x,y) + b_a(x,y)\ \cos\left[\frac{2\pi x}{T_a} + \varphi_a(x,y)\right] \tag{2}$$

where $\varphi_a(x,y)$ refers to the new phase distribution.

The frequency spectrum of reference pattern and deformed pattern are calculated by applying Fourier transform and the results can be expressed as

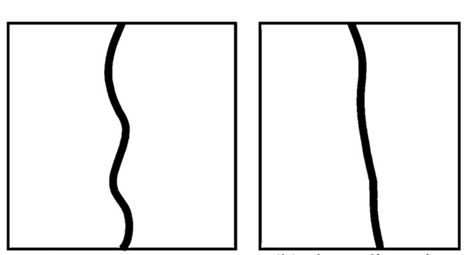
$$G(f_x,y) = A(f_x,y) + C^*(f_x+f,y) + C(f_x-f,y) \tag{3}$$

$$G_a(f_x,y) = A_a(f_x,y) + C_a^*(f_x+f_a,y) + C_a(f_x-f_a,y) \tag{4}$$

Then the corresponding fundamental frequencies are extracted and they are calculated by applying inverse Fourier transform. The results are expressed as

$$g'(x,y) = \frac{1}{2}b(x,y)\exp\left\{i\left[\frac{2\pi x}{T} + \varphi(x,y)\right]\right\} \tag{5}$$

$$g''(x,y) = \frac{1}{2}b_a(x,y)\exp\left\{i\left[\frac{2\pi x}{T_a} + \varphi_a(x,y)\right]\right\} \tag{6}$$



(a) snake-shaped distortion (b) shear distortion

Fig. 3. Snake-shaped distortion and shear distortion.

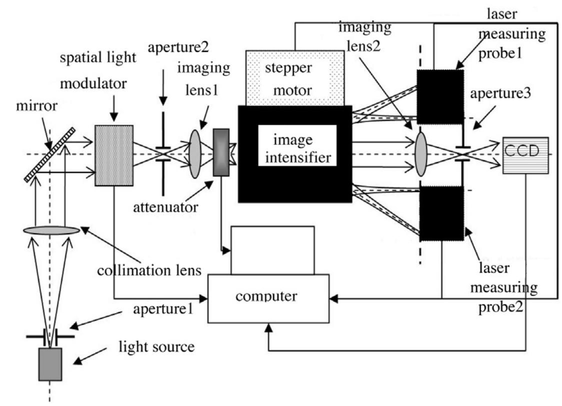


Fig. 4. Schematic of experiment equipments.

The wrapped phase is calculated as follows:

$$\Delta\varphi(x,y) = \varphi_a(x,y) - \varphi(x,y) = img\{\ln[G(x,y)G_a^*(x,y)]\} \tag{7}$$

The corresponding unwrapped phase is calculated by applying the diamond phase unwrapping algorithm [17]. The unwrapped phase can be expressed as

$$\Delta\varphi'(x,y) = \omega_x y + \upsilon_x \quad (x = 1, 2, 3, \ldots, R;\quad y = 1, 2, 3, \ldots, N) \tag{8}$$

The relevant data are save as matrix in actual data processing. So in Eq. (8), R refers to the amount of row and N refers to the amount of column, where ω_x refers to the increment of image magnification in x row.

The maximal ω_x is extracted and the magnification of image intensifier is defined as

$$M = 1 + \max(\omega_x) \tag{9}$$

The deformed phase is calculated as follows:

$$\phi(x,y) = \Delta\varphi'(x,y) - \Delta\bar{\varphi'}(x,y) \tag{10}$$

where $\Delta\bar{\varphi'}(x,y)$ refers to the statistical average.

The pillow-shaped distortion or barrel-shaped distortion of image intensifier is calculated as follows:

$$\begin{cases} \dfrac{\max\{\phi\} - \min\{\phi\}}{2\pi} = \dfrac{dz}{T_a} \\ \dfrac{\max\{\phi\} - \min\{\phi\}}{2\pi} = \dfrac{dt}{T_a} \end{cases} \tag{11}$$

A mathematical expression is defined as

$$D_{SAJ} = \frac{T_a}{2\pi}(\phi_{j(i+1)} - \phi_{ji}) \quad (i = 1, 2, 3, \ldots, R-1;\quad j = 1, 2, 3, \ldots, N) \tag{12}$$

The mathematical expression is defined to calculate the snake-shaped distortion or shear distortion. In a certain column, the snake-shaped distortion has happened if the signs of D_{SAJ} are same, conversely, the shear distortion has happened. The snake-shaped distortion or shear distortion of image intensifier is expressed as

$$d_{SJ} = \max(D_{SAJ}) \tag{13}$$

4. Experimental results

The experiment is performed to verify the feasibility of the proposed method and the experiment equipments are shown in Fig. 4.

The standard sinusoidal fringe pattern is projected into the measuring system by spatial light modulator before the image intensifier is placed in and the corresponding reference pattern is