Optik 124 (2013) 1192–1198

Contents lists available at SciVerse ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Displacement measurement for color images by a double phase-encoded joint fractional transform correlator

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ARTICLE INFO

Article history:
Received 23 October 2011
Accepted 5 March 2012

Keywords:
Fourier optics
Displacement measurement
Double phase-encoding
Color images
Joint fractional transform correlator

ABSTRACT

In this paper, a displacement measurement for color images using double phase-encoded joint fractional transform correlator (DPEJFrTC) is proposed. Color reference and target images are decomposed into red, green and blue channels. New monochromic target and reference images are formed by spatially arranging the three channels. The displacement of color images is obtained using DPEJFrTC by measuring the new monochromic target and reference. In contrast to the classical joint transform correlator (JTC), our technology generates only one sharp peak and the optical structure is more flexible as well as being able to detect the displacement of color images more accurately. A possible optical set-up is suggested.

1. Introduction

Joint transform correlator (JTC) has been widely used in pattern recognition and motion tracking [1–4] since Weaver and Goodman first proposed it in 1966 [5]. Janschek proposed using JTC to measure the shift between imaging devices and the principle axis in order to restore the blurred images and navigate satellites in real-time [6,7]. They made use of JTC to determine the correlation peaks that related to the displacement vector. Yi proposed a hybrid opto-electronic JTC by using one optical transform and up-sampling digital technology, obtaining the result that root-mean-square error (RMSE) of motion measurement accuracy could be controlled below 0.05 pixels [8]. We proposed an image displacement measurement using phase-encoded target JTC [9]. However, these studies involve monochromatic images. Even when the measured images are colored, the above studies involve simply transforming the color images into gray images. In fact, most of visual signals are chromatic. The colors of images are indispensable characteristics for pattern recognition and image registration. Similarities between the shape distributions of each color should be recognized. This is color pattern recognition. Positive recognition means full shape similarity between the target and the reference images in each color distributions [10]. The introduction of color information in pattern recognition and image registration is especially useful when the contours and the intensity distribution do not provide enough information to permit the recognition of images. Thus extending JTC to measure displacement for color images is essential.

Classical JTC has been widely investigated in color pattern recognition by several groups [10–15]. The multichannel single-output color JTC for color pattern recognition is particularly attractive [10], achieving color pattern recognition by applying the classical JTC in multiple channels. The peaks of correlation, however, were not sharp enough. Thus, Alam introduced a fringed-adjusted JTC to [10] improve performance of color pattern recognition [11]. A fringe-adjusted filter was applied to each channel to achieve excellent correlation discrimination. And the multichannel single-output color JTC produced 15 peaks in the correlation plane [10]. It is not easy, however, to obtain the location of cross-correlation peaks that represented the coherence level between the reference and the target image for all color channels. A new system of multi-channel single-output joint fractional Fourier transform correlator for color pattern recognition was proposed by Jin [12]. They obtained only three correlation peaks at the output plane. Hsieh presented a JTC for color image recognition by using three liquid-crystal spatial light modulators, experimentally obtaining the correlation peaks of red, green, and blue [13]. Some researchers adopted color encoding to implement color pattern recognition [14,15]. Nicolás considered the color distribution as the third dimension and proposed an encoding of the 3D images into 2D images in order to perform their 3D correlation in a convergent optical correlator [14]. Alam proposed a new 3D color pattern recognition technique, exploiting the concept of a fringe-adjusted JTC and CIELab color space, yields better discrimination and sharper and stronger correlation

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0030-4026/$ – see front matter
http://dx.doi.org/10.1016/j.ijleo.2012.03.024

peak intensity, as compared with a classical JTC with conventional red–green–blue (RGB) components [15]. To our knowledge, however, no one has attempted to apply joint fractional transform correlator to displacement detection for color images.

In this paper we propose a displacement measurement for color images based on double phase-encoding JFrTC (DPEJFrTC). In this technology the color reference image is separated into the RGB channels, displaying on a monochromatic plane and phase-encoded by a random phase-mask. The color target image is also separated into the RGB channels and overlaid with phase-encoded monochromatic reference image to form the input image, resulting in a single sharp correlation peak through DPEJFrTC. The input plane is gray scaled, thus real-time operation is possible with the use of spatial light modulators (SLMs). The displacement between the color reference and the color target image is obtained by measuring the position of the cross-correlation peak. Also, due to the fractional Fourier transform, our optical set-up could be more flexible and easier to implement when we choose different fractional order p value, in contrast to classical JTC with fixed 4f systems.

2. Color image displacement detection based on DPEJFrTC

First, we decompose color images into three channels which consist of red, green and blue channels. For a color reference image, we decompose it into r_R, r_G, r_B which represent the red, the green and the blue channel respectively. The new monochromic reference is formed by specially arranging the three components shown as Fig. 1(a):

$$r(x, y) = r_R(x, y - a) + r_G(x, y) + r_B(x, y + a) \quad (1)$$

a in Eq. (1) is a constant space between each channel. The color target image has a displacement (x_i, y_i) relative to the reference image; thus, the new monochromic target is formed as Fig. 1(b) and expressed as:

$$t(x, y) = t_R(x + x_i, y - a + y_i) + t_G(x + x_i, y + y_i) + t_B(x + x_i, y + a + y_i), \quad (2)$$

where t_R is the red component of the color target image, t_G is the green component of the color target image, and t_B is the blue component of the color target image.

Refregier and Javidi proposed double phase encoding and applied it in optical image encryption and decryption [16]. We modified and applied it to gray image displacement measurement [9]. Consider a random phase function $\Phi(u,v)$ in Fourier domain, and define a phase mask $\Theta(u,v)$.

$$\Theta(u, v) = \exp[-j\Phi(u, v)] \quad (3)$$

$$\phi(x, y) = ifft2[\Theta(u, v)] \quad (4)$$

In Eq. (3), $\Phi(u,v)$ is a random phase function uniformly distributed between 0 and 2π in Fourier domain, and j denotes an imaginary unit. In Eq. (4) $ifft2$ is 2D inverse Fourier transform function. We use $\phi(x,y)$ to encode the monochromatic reference image $r(x,y)$ as follows,

$$r''(x, y) = r(x, y) \otimes \phi(x, y) \quad (5)$$

We overlap the phase-encoded monochromatic reference with the monochromatic target image to form the monochromatic input image. Thus the joint input image is given by:

$$vf(x, y) = \{r_R(x, y - a) + r_G(x, y) + r_B(x, y + a)\} \otimes \phi(x, y) + [t_R(x + x_i, y - a + y_i) + t_G(x + x_i, y + y_i) + t_B(x + x_i, y + a + y_i)] \quad (6)$$

Its Fourier spectrum is expressed as follows:

$$F(u, v) = R_R(u, v)\Theta(u, v)\exp(iva) + R_G(u, v)\Theta(u, v) + R_B(u, v)\Theta(u, v)\exp(-iva) + T_R(u, v)\exp(-iux_i - ivy_i + iva) + T_G(u, v)\exp(-iux_i - ivy_i) + T_B(u, v)\exp(-iux_i - ivy_i - iva) \quad (7)$$

where $R(u,v)$,$T(u,v)$ are Fourier transformation of $r(x,y)$,$t(x,y)$. And joint power spectrum (JPS) is obtained by:

$$\begin{aligned}
\mathrm{JPS}(u, v) &= |F(u, v)|^2 \\
&= R_R(u, v)^2 + R_G(u, v)^2 + R_B(u, v)^2 + T_R(u, v)^2 \\
&\quad + T_G(u, v)^2 + T_B(u, v)^2 \\
&\quad + 2|R_R(u, v)||R_G(u, v)|\cos\left(\phi_{R_R}(u, v) - \phi_{R_G}(u, v) + i2va\right) \\
&\quad + 2|R_R(u, v)||R_B(u, v)|\cos\left(\phi_{R_R}(u, v) - \phi_{R_B}(u, v) + i4va\right) \\
&\quad + R_R(u, v)\Theta(u, v)T_R(u, v)^* \exp(iux_i + ivy_i) \\
&\quad + T_R(u, v)\exp(-iux_i - ivy_i)R_R(u, v)^*\Theta(u, v)^* \\
&\quad + R_R(u, v)\Theta(u, v)T_G(u, v)^* \exp(iux_i + ivy_i + iva) \\
&\quad + T_G(u, v)\exp(-iux_i - ivy_i - iva)R_R(u, v)^*\Theta(u, v)^* \\
&\quad + R_R(u, v)\Theta(u, v)T_B(u, v)^* \exp(iux_i + ivy_i + i2va) \\
&\quad + T_B(u, v)\exp(-iux_i - ivy_i - i2va)R_R(u, v)^*\Theta(u, v)^* \\
&\quad + 2|R_G(u, v)||R_B(u, v)|\cos\left(\phi_{R_G}(u, v) - \phi_{R_B}(u, v) + i2va\right) \\
&\quad + R_G(u, v)\Theta(u, v)T_R(u, v)^* \exp(iux_i + ivy_i - iva) \\
&\quad + T_R(u, v)\exp(-iux_i - ivy_i + iva)R_G(u, v)^*\Theta(u, v)^* \\
&\quad + R_G(u, v)\Theta(u, v)T_G(u, v)^* \exp(iux_i + ivy_i) \\
&\quad + T_G(u, v)\exp(-iux_i - ivy_i)R_G(u, v)^*\Theta(u, v)^* \\
&\quad + R_G(u, v)\Theta(u, v)T_B(u, v)^* \exp(iux_i + ivy_i + iva) \\
&\quad + T_B(u, v)\exp(-iux_i - ivy_i - iva)R_G(u, v)^*\Theta(u, v)^* \\
&\quad + R_B(u, v)\Theta(u, v)T_R(u, v)^* \exp(iux_i + ivy_i - i2va) \\
&\quad + T_R(u, v)\exp(-iux_i - ivy_i + i2va)R_B(u, v)^*\Theta(u, v)^* \\
&\quad + R_B(u, v)\Theta(u, v)T_G(u, v)^* \exp(iux_i + ivy_i - iva) \\
&\quad + T_G(u, v)\exp(-iux_i - ivy_i + iva)R_B(u, v)^*\Theta(u, v)^* \\
&\quad + R_B(u, v)\Theta(u, v)T_B(u, v)^* \exp(iux_i + ivy_i) \\
&\quad + T_B(u, v)\exp(-iux_i - ivy_i)R_B(u, v)^*\Theta(u, v)^* \\
&\quad + 2|T_R(u, v)||T_G(u, v)|\cos\left(\phi_{T_R}(u, v) - \phi_{T_G}(u, v) + i2va\right) \\
&\quad + 2|T_R(u, v)||T_B(u, v)|\cos\left(\phi_{T_R}(u, v) - \phi_{T_B}(u, v) + i4va\right) \\
&\quad + 2|T_G(u, v)||T_B(u, v)|\cos\left(\phi_{T_R}(u, v) - \phi_{T_B}(u, v) + i2va\right)
\end{aligned} \quad (8)$$

* denotes conjugate operator. ϕ_{R_R}, ϕ_{R_G}, ϕ_{R_B}, ϕ_{T_R}, ϕ_{T_G}, ϕ_{T_B} are phase part of $R_R(u, v)$, $R_G(u, v)$, $R_B(u, v)$, $T_R(u, v)$, $T_G(u, v)$, $T_B(u, v)$, respectively. Then we multiply Eq. (8) with the same phase mask $\Theta(u,v)$, and we obtain phase-encoded JPS (PJPS):

$$\mathrm{PJPS} = \mathrm{JPS}(u, v)\Theta(u, v) \quad (9)$$

If we apply an inverse Fourier transform to Eq. (9), it will produce a huge cross-correlation as well as many small noises. Items including the phase mask $\Theta(u,v)$ in Eq. (9) will become into system noises randomly distributed in the output plane. The amplitude of these system noises is much smaller than the amplitude of the cross-correlation between the reference and the target image. In order to illustrate the mathematical expression of the cross-correlation's