Optoelectronic Correlator Based on YUV Color Model with Multi-level Quantized Reference Function for Chromatic Image Recognition

Tengwen Chen, Chulung Chen*, Chengyu Liu, and Yuming Chen

***Abstract*—We utilize Mach-Zehnder joint transform correlator based on YUV color model for chromatic pattern recognition. The multi-channel joint transform correlator requires a larger liquid crystal spatial light modulator (LCSLM) to achieve the chromatic pattern recognition. YUV color model contributes to utilize two components of chrominance on recognition. We utilize minimum average correlation energy method to achieve the distortion invariant pattern recognition. The multi-level quantized reference function is applied to design the filter to be more suitable for realizing the input plane of liquid crystal spatial light modulator. Numerical results for rotated distortion and quantized level are presented.**

***Index Terms*—Chromatic pattern recognition, Mach-Zehnder joint transform correlator, YUV color model.**

I. Introduction

Recently, optical correlation has been investigated for pattern recognition. In 1964, VanderLugt proposed the VanderLugt correlator (VLC) [1]. However, the VLC system is difficult to be accurately aligned along the optical axis. To improve this problem, Weaver and Goodman proposed joint transform correlator (JTC) [2] in 1966. Due to the lack of adequate devices, JTC was substantially stagnant until the real-time programmable JTC was proposed by Yu and Lu in 1984 [3]. JTC system put the reference and target images on the input plane simultaneously to improve the problem of alignment. Nevertheless, the classical JTC has the strong zero order term on the output plane, which yields the poor recognition capability. The phase shifting technique and joint transform power spectrum (JTPS) subtraction were proposed to remove the zero order term [4,5]. In this paper, the Mach-Zehnder JTC (MZJTC) [6] can accomplish the removal of zero order term processing in only one step directly. The location and orientation of target are often unknown for real application. Chen et al. [7] utilized the minimum average correlation energy (MACE) method [8] based on the Lagrange multipliers to design the reference function. Recently, the multi-level quantized reference function (MQRF) was constructed by Chen et al. [9]. The limited quantized range is suitable for realizing the input plane of JTC system. Most of the optical recognition implementations are based on monochromatic images. In 1996, Deutsch proposed a multi-channel single-output JTC [10] based on the red, green and blue.

In this paper, we present a novel MZJTC with two channels based on YUV color model for chromatic pattern recognition. The characteristic of YUV color model contributes to utilize two components of chrominance to achieve recognition instead of the three channels system. Moreover, these two components will be synthesized into the reference function by MQRF filter.

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II. Analysis

YUV color model is a color-encoding system utilized in broadcast television systems. It transforms RGB source into one luminance and two chrominance components by linear conversion. The relationships between RGB and YUV are shown below.

$$Y = 0.299R + 0.587G + 0.114B, \qquad (1)$$

$$U = 0.493(B - Y), \qquad (2)$$

and

$$V = 0.877(R - Y), \qquad (3)$$

The structure of optical correlator is shown in Fig. 1. A laser is used to be the light source. At first, we define the position functions of reference and target images on the input planes, these are

$$r(x, y) = \sum_{i=1}^{2} r_i(x + x_i, y - b), \qquad (4)$$

and

$$f(x, y) = \sum_{j=1}^{2} f_j(x + x_j, y + b), \qquad (5)$$

where $x_1 = -a$; $x_2 = a$; $r(x, y)$ represents the position function of reference image at RLCSLM1; $f(x, y)$

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represents the position function of target image at RLCSLM2. After coming out of RLCSLM1 and RLCSLM2, two lights will take the information and be Fourier transformed by Fourier lens (FLs). The lights occur fractional reflection and transmission at BS3. Joint transform power spectrums (JTPSs) of two light fields will be detected by CCD1 and CCD2. We connect the outputs to the electronic subtractor (ES) to remove the zero order term as

$$I_o = \left|L_2(u,v)\right|^2 - \left|L_1(u,v)\right|^2. \quad (6)$$

Using the Stokes relations from optics knowledge, we obtain $\beta_1 = -\beta_2$. In addition, we assume that $|\alpha_1| = |\beta_1|$ and $|\alpha_2| = |\beta_2|$ in this study. The α_1 and β_1 are repectively the transmission and reflection coefficients of the BS3 for light incident from FL1, α_2 and β_2 are repectively the transmission and reflection coefficients of the BS3 for light incident from FL2. Then Eq. (6) can be rewritten as

$$\begin{aligned} I_o &= 4\cdot\sum_{i=1}^{2}\sum_{j=1}^{2}\left|R_i(u,v)\right|\left|F_j(u,v)\right| \\ &\cdot \mathrm{Re}\left\{\alpha_1\beta_1^*\cos\left[2\pi\left((x_j - x_i)u + 2bv\right) - \phi_{R_i}(u,v) + \phi_{T_j}(u,v)\right]\right\}, \end{aligned} \quad (7)$$

where the symbol * denotes the complex conjugate; ϕ_{R_i} and ϕ_{F_j} are the phase of $R_i(u,v)$ and $F_j(u,v)$, respectively. The JTPS with no zero order term is sent to RLCSLM3. Finally, the cross-correlation output will be obtained in CCD3 as follows:

$$\begin{aligned} o(x,y) &= \sum_{i=1}^{2}\sum_{j=1}^{2}\left|c_{ij}(-x,-y)\right|^2 \otimes \delta(x - x_i + x_j, y - 2b) \\ &+ \sum_{i=1}^{2}\sum_{j=1}^{2}\left|c_{ij}^*(x,y)\right|^2 \otimes \delta(x + x_i - x_j, y + 2b), \end{aligned} \quad (8)$$

where $c_{ij}(x,y) = r_i(x,y)\circ f_j(x,y)$ is the cross-correlation between $r_i(x,y)$ and $f_j(x,y)$. The symbol $\circ$ denote the correlation operations; $\otimes$ denote the convolution operations; δ is the Dirac delta function.

Besides, we minimize the average correlation energy for all training images while maintaining the correlation peak height at a specified value. By using the Lagrange multipliers technique, the optimum reference function can be obtained in Fourier domain as follows:

$$\hat{H} = \hat{D}^{-1}\hat{F}\left[\hat{F}^{+}\hat{D}^{-1}\hat{F}\right]^{-1}\hat{C}^*, \quad (9)$$

where $\hat{F}$ is a matrix in which column vectors represent the sampled Fourier transforms of the training images; $\hat{D}$ is a diagonal matrix in which each diagonal element comes from the average power spectrum for the corresponding pixel. $\hat{C}$ is the designed correlation peak vector in which entries can be specified by the user as the same value to yield equal correlation peaks.

The reference function can be obtained by inverse Fourier transform of $H(u,v)$ as follows:

$$h(x,y) = \Im^{-1}\left\{H(u,v)\right\}. \quad (10)$$

Subsequently, we quantize this reference function in spatial domain with finite integer levels. The final quantized reference function can be expressed as

$$r(x,y) = Round\left(\frac{h(x,y)}{M}\times 2^Q\right), \quad (11)$$

where M is the maximum absolute value of $h(x,y)$, Q is the quantization parameter, $Round(K)$ function rounds the elements of K to the nearest integer.

III. Numerical Results

In this work, we chose the colorful fish with 128 × 128 pixels to be the original pattern, as shown in Fig. 2. Furthermore, we separate the image's information into YUV color model to obtain the U and V grayscale images. The training image set contains 15 color images with different rotation angles from -14° to 14 ° (in steps of 2 °). The reference images are synthesized by the training images to achieve the distortion invariance. Subsequently, we quantize this reference images with finite integer levels, as shown in Fig. 3. We selected the unrotated image to be the target. The three-dimensional correlation output profile for $Q = 7$ is shown in Fig. 4.

In order to test the ability of distortion tolerance, we utilized each rotation angle to form the input image from -14° to 14 °, and obtained the correlation peak intensities (CPI) for $Q = 7$, as shown in Fig. 5.

IV. Conclusion

In this work, we propose a two-channel MZJTC based on YUV color model for chromatic pattern recognition. It removes the zero order term in one step directly and reduces the size requirement of liquid crystal spatial light modulator. From the three-dimensional correlation output profile, we observe the sharp desired correlation peak obviously. This system shows the good recognition ability. Therefore, the two-channel MZJTC based on YUV color model has the accepted recognition ability for chromatic pattern recognition.

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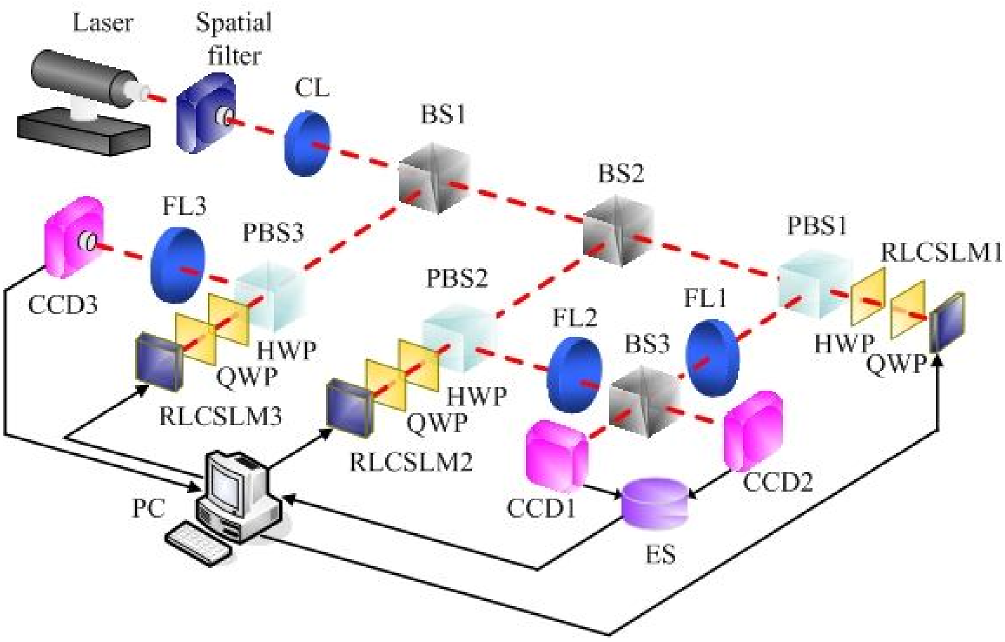

Figure 1. The structure of a MZJTC system.

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Figure 2. The original pattern.

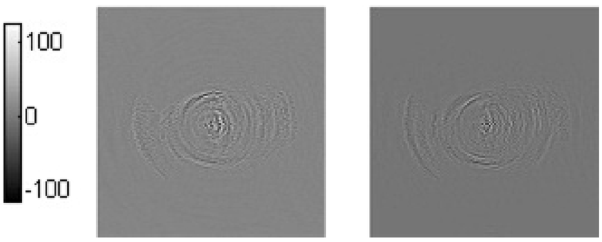

Figure 3. The quantized reference images of U and V components for Q=7.

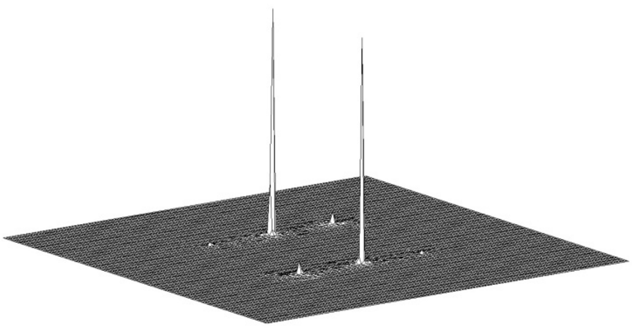

Figure 4. The 3D correlation output profile.

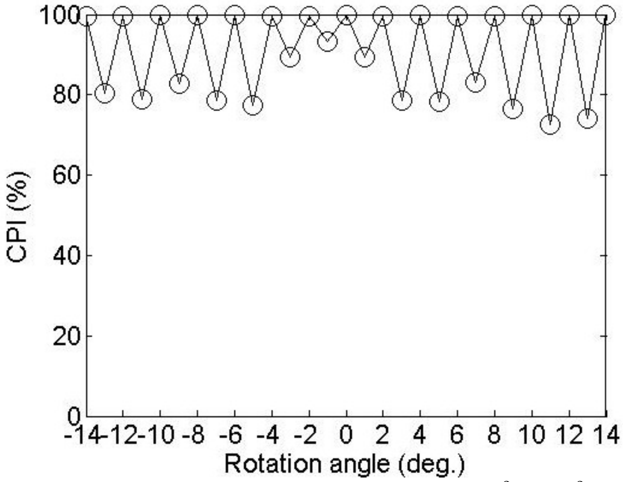

Figure 5. CPI versus rotation angle from -14^{o} to 14^{o}.

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