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Robust Target Detection Employing Log-Polar Transformation and Multiple Phase-Shirted Joint Transform Correlation

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Abstract: Target detection techniques suffer from slow speed, poor discrimination ratio, and failure in variable environmental conditions. Optical multiple phase-shifted reference based joint transform correlation (MRJTC) technique is developed, which proves to be very efficient and sensitive detecting a potential target at a very high speed. A fringe-adjusted filter is designed to enhance the discrimination ratio between a target and non-target objects. In addition, a log-polar transform algorithm is incorporated in the MRJTC technique to make the pattern recognition invariant to scale and rotation variations. The peak-to-side lobe ratio is measured and compared to a threshold at the correlation plane to detect and/or track a pattern of interest in an unknown input scene. Computer simulation results verify the robustness of the proposed target detection.

Keywords: Join transform correlation, Joint power spectrum, Phase encoding, Log-polar transformation, Fringe-adjusted filter, Target detection.

1. Introduction

Target detection is an automatic system to identify a pattern of interest in an unknown input scene. Optical joint transform correlation (JTC) technique has proven to be successful in detecting a target at a high speed by using optical lens and spatial filters. Additional advantages are that it allows real-time updating of the reference image, permits parallel Fourier transformation of the reference image and input scene, operates at video frame rates and eliminates the precise positioning requirement of a complex matched filter in the Fourier plane [1-2]. However, the classical JTC technique suffers from poor correlation discrimination, wide sidelobes, conjugate correlation peak, strong zero-order correlation, and failure to perform in noisy environment. Several modifications of the classical JTC technique have been proposed in the literature to alleviate these problems, which include binary JTC [3], phase-only JTC [4], fringe-adjusted JTC (FJTC) [5], shifted phase-encoded JTC [6], and complementary-reference and complementary-scene JTC [7]. However, majority of these techniques are not as efficient in detecting targets with sufficiently high discrimination from non-target objects and also not having a simple system architecture and not being able to perform at high speed operation for real-time pattern recognition applications. Additional challenge is to make the target detection performance invariant to distortions due to scale and rotation variations of the targets in the input scene.

The objective of this paper is to develop a novel target detection technique employing log-polar transformation and multiple phase-shifted-reference JTC (MRJTC) technique. The author previously developed the MRJTC algorithm that processes four phase-shifted reference images with the same input scene and hence removes all the unwanted correlation terms and produces a single and highly discriminant correlation peak for each potential target [8]. This paper incorporates the log-polar transformation to images that are fed to the MRJTC algorithm in order to make the correlation output invariant to scale and rotation variations. Computer simulation results show that the proposed technique is successful in recognizing the potential targets present in a real-life input scene with complex background conditions.

2. Performance Analysis

Fig. 1 shows the schematic diagram of the target detection system. The reference image of the target, $r(x, y)$, in the Cartesian coordinates is first transformed to the log-polar coordinate system

$$r_t(\rho, \theta) = LPT\{r(x, y)\}, \tag{1}$$

where LPT denotes a log-polar transformation, and ρ and θ are the logarithm of the radius and the angular position in the log-polar coordinate system, respectively, calculated using the following formulas:

$$\rho = log\sqrt{(x - x_0)^2 + (y - y_0)^2} \tag{2}$$

and

$$\theta = \tan^{-1}\left(\frac{y - y_0}{x - x_0}\right), \tag{3}$$

where (x_0, y_0) is the center pixel of the image in the Cartesian coordinate. The transformed reference image of Eq. (1) is then phase-shifted by 0, 90, 180 and 270 degrees, respectively and fed to four parallel processing channels.

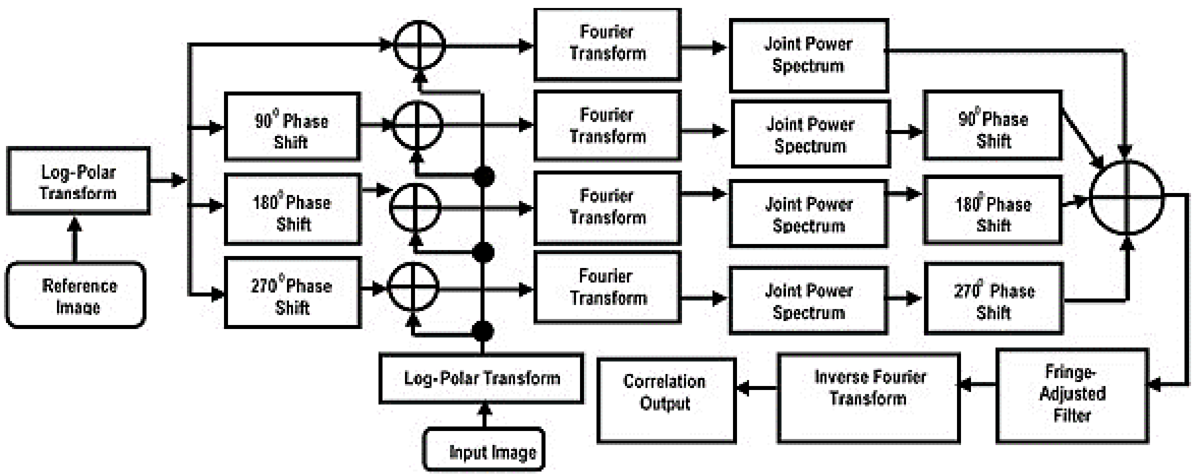


Fig. 1. Block diagrams of the proposed target detection system.

The given input scene, $t(x, y)$, containing unknown objects is also transformed to the log-polar domain

$$t_t(\rho, \theta) = LPT\{t(x, y)\} \tag{4}$$

The transformed input image of Eq. (4) is introduced to transformed reference image in four separate channels and four joint images are formed as follows.

$$f_1(x, y) = r_t(x, y) + t_t(x, y), \tag{5}$$

$$f_1(x, y) = jr_t(x, y) + t_t(x, y), \tag{6}$$

$$f_1(x, y) = -r_t(x, y) + t_t(x, y), \tag{7}$$

$$f_1(x, y) = -jr_t(x, y) + t_t(x, y) \tag{8}$$

These joint images are now Fourier transformed, where from four different joint power spectra (JPS) are obtained.

$$\begin{aligned} P_1(u, v) &= |F_1(u, v)|^2 \\ &= |R_t(u, v)|^2 + |T_t(u, v)|^2 \\ &+R_t(u, v)T_t^*(u, v) + R_t^*(u, v)T_t(u, v), \end{aligned} \tag{9}$$

$$\begin{aligned} P_2(u, v) &= |F_2(u, v)|^2 \\ &= |R_t(u, v)|^2 + |T_t(u, v)|^2 \\ &+jR_t(u, v)T_t^*(u, v) - jR_t^*(u, v)T_t(u, v), \end{aligned} \tag{10}$$

$$\begin{aligned} P_3(u, v) &= |F_3(u, v)|^2 \\ &= |R_t(u, v)|^2 + |T_t(u, v)|^2 \\ &-R_t(u, v)T_t^*(u, v) - R_t^*(u, v)T_t(u, v), \end{aligned} \tag{11}$$

$$\begin{aligned} P_4(u, v) &= |F_4(u, v)|^2 \\ &= |R_t(u, v)|^2 + |T_t(u, v)|^2 \\ &-jR_t(u, v)T_t^*(u, v) + jR_t^*(u, v)T_t(u, v) \end{aligned} \tag{12}$$

Each of the JPS terms in Eqs. (9)-(12) contains a number of terms to produce auto-correlation and cross-correlation terms as is the case for a classical JTC technique. However, the JPS signals can be combined by incorporating an algebraic operation as given by

$$\begin{aligned} P(u,v) &= P_1(u,v) + jP_2(u,v) - P_3(u,v) \\ &\quad - jP_4(u,v) \\ &= 4R_t^*(u,v)T_t(u,v) \end{aligned} \tag{13}$$

The modified JPS signal in Eq. (13) eliminates all unwanted correlation terms and also produces the correlation peak exactly at the target location. Next a fringe-adjusted filter is incorporated to enhance the correlation performance.

$$H(u,v) = \frac{C(u,v)}{D(u,v) + |R(u,v)|^2}, \tag{14}$$

where $C(u,v)$ and $D(u,v)$ are either constants or functions of u and v. The parameter $C(u,v)$ is adjusted to avoid having an optical gain greater than unity, while $D(u,v)$ is used to overcome the pole problem otherwise associated with a normal filter. Since the power spectra of the reference image can be pre-calculated and stored, implementation of the FAF also will not adversely impact the processing speed of the pattern recognition system.

The JPS in Eq. (13) is multiplied by the FAF transfer function in Eq. (14) to yield an enhanced JPS as given by

$$P_f(u,v) = \frac{4C(u,v)4R_t^*(u,v)T_t(u,v)}{D(u,v) + |R(u,v)|^2} \tag{15}$$

Inverse Fourier transformation of this signal results in a single and very sharp correlation peak for each potential target of the reference class present in the input scene.

Finally, the target detection decision is made by measuring the peak correlation value, $c_p(x, y)$, and correlation values around the peak, $c_i(x, y)$. Then the peak-to-side lobe ratio (PSR) is determined as

$$\mathrm{PS}R = \frac{c_p(x,y)}{\sum_{i=1,i\neq p} c_i(x,y)} \tag{16}$$

The PSR value is compared to a threshold value to determine if the correlation peak belongs to a target.

3. Simulation Results

The proposed target detection system is simulated using MATLAB program. Fig. 2(a) shows a binary image with a size of 32×32 pixels.

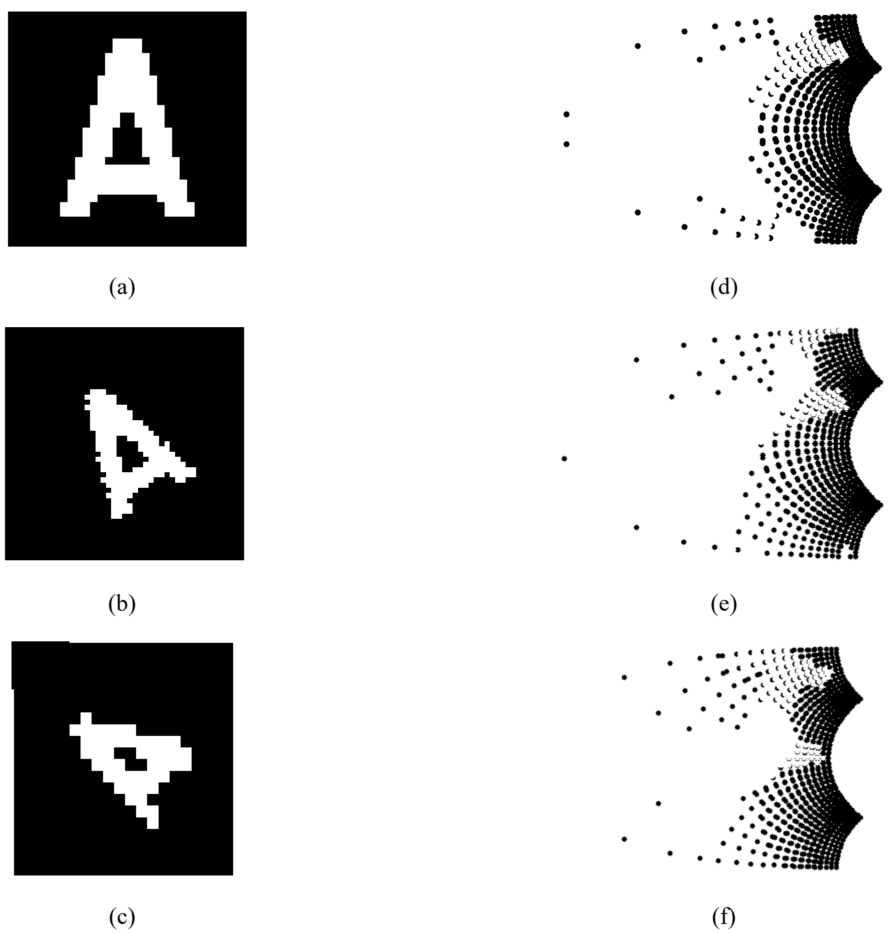
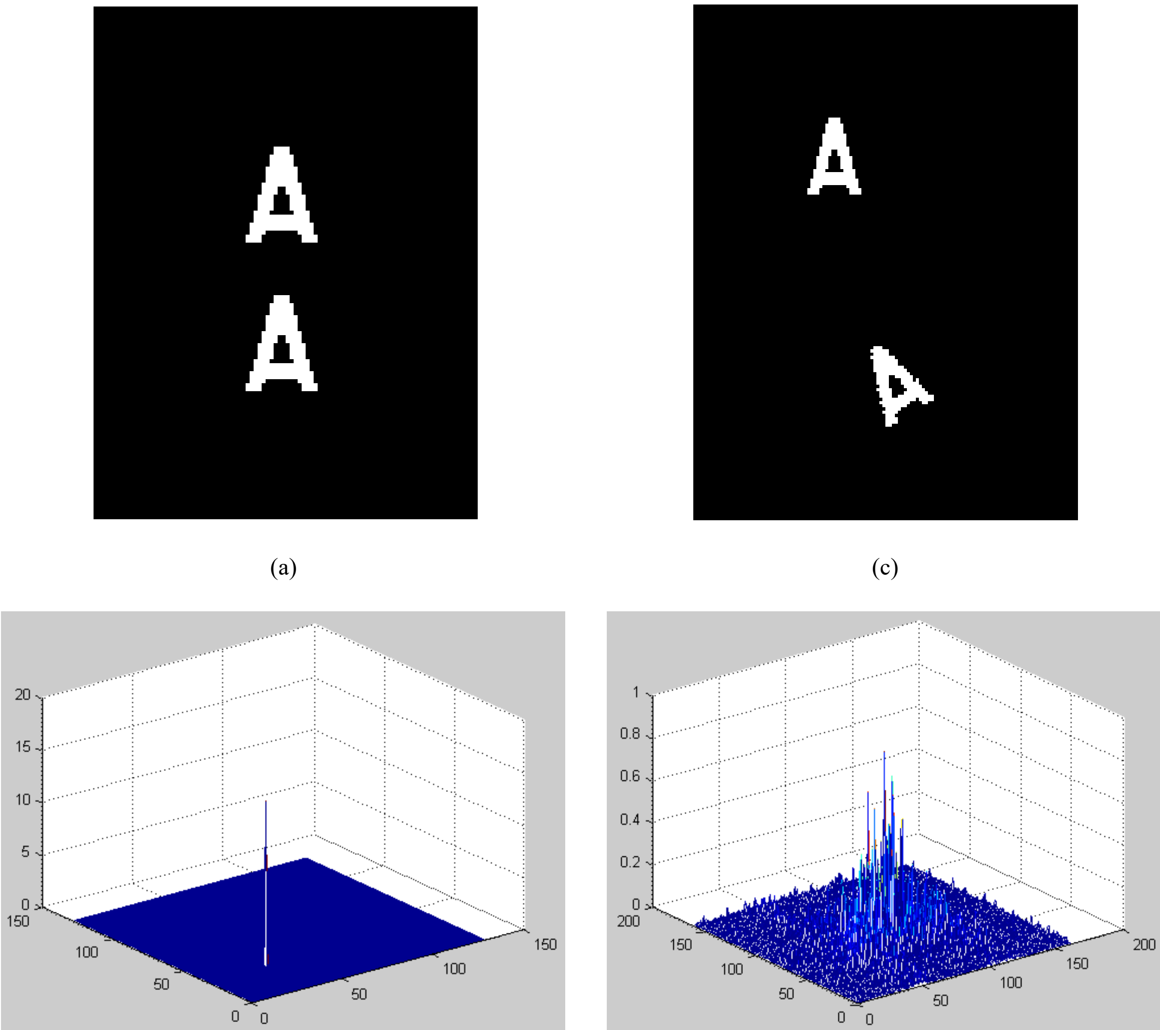


Fig. 2. Log-polar transformation of images: (a)-(c) spatial domain images, (d)-(f) transformed images.

Then the image is rotated by 30 and 60 degree, respectively, as depicted in Fig. 2(b)-(c). These images are then log-polar transformed as shown in Fig. 2(d)-(f). It can be observed that the in-plane rotation of the image in the spatial domain does not affect the transformed image significantly.

The correlation performance of the proposed technique is evaluated using some test images. Fig. 3(a) shows the joint image where the top half of the image contains the reference object from Fig. 2(a) and the bottom half contains the unknown input scene. It is obvious from the correlation output shown in Fig. 3(b) that the proposed system is highly efficient in producing a very sharp correlation peak corresponding to the target object present in the input scene. Next, we used a rotated image in the input scene while keeping the same reference object as shown in Fig. 3(c). The correlation performance shown in Fig. 3(d) indicates a failure in detecting the target with distinction.



(a) (c)

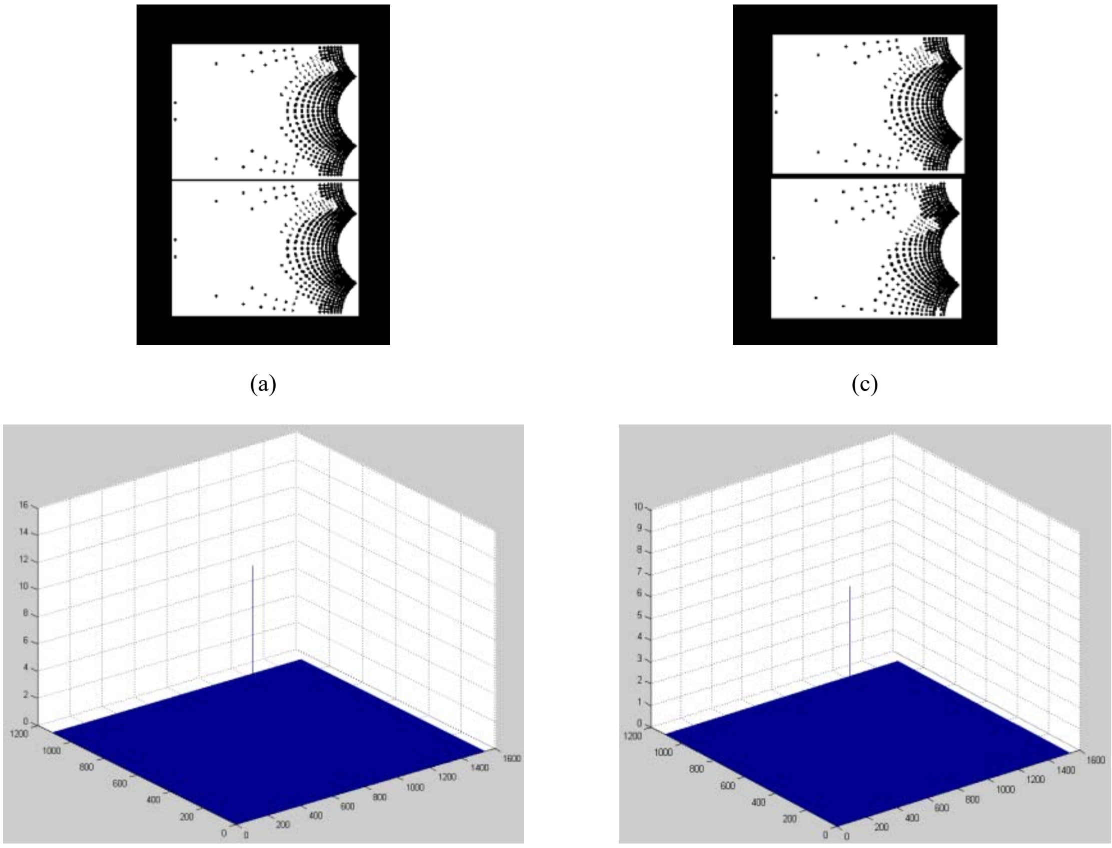
(b) (d)

Fig. 3. Correlation performance for images in the spatial domain: (a), (c) joint input scene; (b), (d) correlation output.

Then the simulation experiment was carried out employing the log-polar transformation. As before, a joint image was formed using the transformed reference image and unknown input scene in the top half and lower half of the plane, respectively. Fig. 4(a) and Fig. 4(c) show two test joint images. The corresponding correlation outputs are depicted in Fig. 4(b) and Fig. 4(d), respectively. It can be obvious that the proposed target detection technique has been successful in detecting a target even with a significant amount of rotational distortion.

4. Conclusions

A robust and effective pattern target detection system is proposed in this paper, which requires simple architecture and hence can be easily implemented using optics for fast and precision performance. Computer simulation results demonstrate that the proposed technique can detect a target is various practical conditions, including scale and rotation variations. The algorithm can be built with optics, which will yield a promising candidate for real-life applications in the field of target detection and tracking, biometric authentication and industry automation.



(a) (c)

(b) (d)

Fig. 4. Correlation performance in the transformed domain: (a), (c) joint input scene; (b), (d) correlation output.

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