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New Architectures and Algorithm for Optical Pattern Recognition using Joint Transform Correlation Technique

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Abstract

Recently, there is increasing interest in using joint transform correlation (JTC) technique for optical pattern recognition. In this technique, the target and reference images are jointed together in the input plane and no matched filter is required. In this paper, the JTC is investigated using simulation technique. A new discrimination decision algorithm is proposed to recognize the correlation output for different object shapes (dissimilar shapes). Also, new architectures are proposed to overcome the main problems of the conventional JTC.

معماريات و خوارزمية جديدة لتمييز الأ اط الضوئي باستعمال تقنية التحويلة ا شتركة

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ا لاصة

مؤخراً تزايد إستعمال تقنية ويلة التطابق ا شتركة (JTC) ييز الأ اط الضوئي. هذه التقنية يتم إدخال صور ا دف و ا صدر معاً آن واحد و صورة مشتركة حيث لا يستعمل ا رشح ا تناظر هيكلها. هذا العمل دراسة التقنية باستعمال عملية ا اكـاة إقتـراح خوارزمية جديدة لقرار التمييز النهائي من إخراج التطابق وللأشكال ا ختلفة والغ ا تشابة. كما اقتراح معماريات جديـدة للـتخلص مـن ا شاكل الرئيسية لتقنية التحويلة ا شتركة الأعتيادية.

1. Introduction

JTC research remained practically stagnant until 1984, when a near real time programmable JTC was developed by YU et al. Since then, JTC became a viable tool for various pattern recognition and optical processing applications [1].

Conventional joint transform correlation technique has been found to suffer from large sidelobes, strong zero-order terms, wide correlation bandwidth, and low discrimination sensitivity [2]. Many modified JTC techniques have been proposed in the literature to yield sharper correlation peak intensity and higher signal-to-noise ratio such as binary JTC [3] and fringe-adjusted JTC [4]. The binary JTC technique has been found to be superior to the conventional JTC in terms of the correlation peak intensity, correlation width, and discrimination sensitivity. However, a binary JTC involves computationally intensive joint power spectrum (JPS) binarization, which limits the system processing speed [5]. Further, for the case of multi-object, this technique introduces harmonic correlation peaks. The fringe-adjusted JTC scheme has been found to yield better correlation results than the binary JTC and gives excellent correlation performance and high discrimination sensitivity for single or/and multi-object pattern recognition [1,2]. But for multi-object and multi-reference simultaneously state, especially if there are multi-uncorrelated or/and dissimilar objects in the input scene, there are little works have been reported in the literature [6].

In this paper, the double JTC (DJTC) with its new discrimination algorithm is introduced to solve some of these problems and to offer high sensitivity for output discrimination. However, this technique does not solve the problem of wide correlation width. To overcome the problem of large width of the correlation peak intensity, the DJTC technique is normalized here. The new proposed technique is called normalized DJTC.

The normalized DJTC is applicable for multi-target and multi-reference pattern recognition. The performance of the conventional JTC technique is investigated here via computer simulation using active software. This software is used to simulate the results of different points of the system. Fast Fourier Transform (FFT) technique is used to get the Fourier transform and correlation results. A 8×8 pixels test images are used for the reference and input scene objects represented by black-white level. The images are combined and zero padded to form a 128×128 pixels input joint image (1).

(1) The images that have been shown are representation of which are used.

2. Review of JTC

2.1 Architecture

A conventional JTC architecture is shown in Figure (1) [1], where the reference and the input scenes are displayed side by side in the input plane using a spatial light modulator (SLM) device. This input is illuminating by a laser light source. Two Fourier lenses are used along with other SLM for displaying the joint power spectrum (JPS), which is detected by charge coupled devices (CCDs)[7,8].

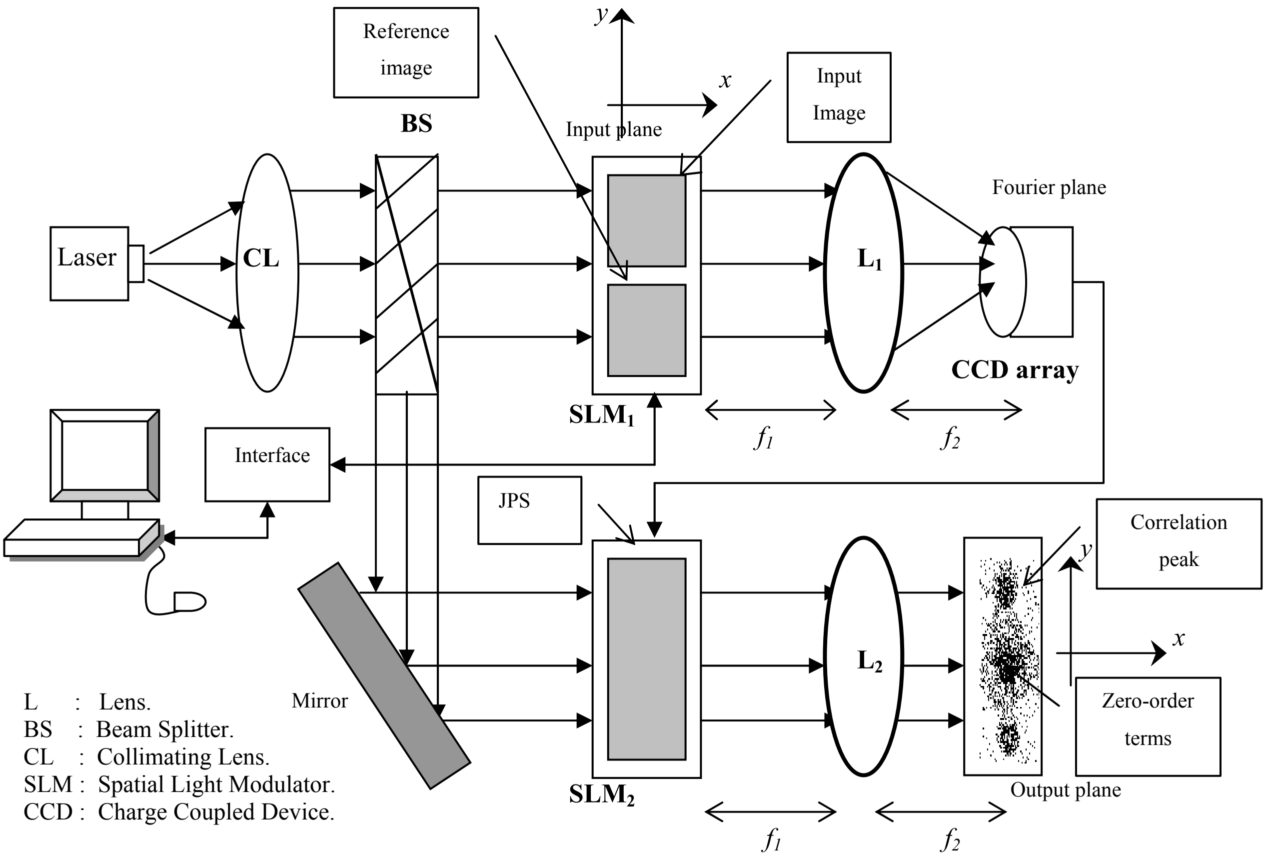

Fig.(1): Conventional JTC architecture.

2.2 Arithmetic

Assume that $\sum_{i=1}^{M} r_i(x+x_i, y-y_i)$ represents the M reference images and $\sum_{k=1}^{N} t_k(x-x_k, y-y_k)$ represents the N input object images in the input plane. Here (x_i, y_i) and (x_k, y_k) are the spatial locations of the M references and the N input objects, respectively. The input joint image $f(x,y)$ can be expressed as [8]

$$f(x,y)=\sum_{i=1}^{M} r_i(x+x_i, y-y_i)+\sum_{k=1}^{N} t_k(x-x_k, y-y_k) \tag{1}$$

The corresponding distribution in the Fourier plane is given by

$$F(u,v)=\sum_{i=1}^{M} R_i(u,v)e^{j(uxi-vyi)}+\sum_{k=1}^{N} T_k(u,v)e^{-j(uxk+vyk)}. \tag{2}$$

where $F(u,v)$, $R_i(u,v)$ and $T_k(u,v)$ are the Fourier transforms of $f(x,y)$, $r_i(x,y)$ and $t_k(x,y)$, respectively.

The JPS in the Fourier plane can be detected by means of a square-law detector. The corresponding intensity distribution is given by

$$\begin{aligned}|F(u,v)|^2 &= \sum_{i=1}^{M}|R_i(u,v)|^2+\sum_{k=1}^{N}|T_k(u,v)|^2 \\ &+\sum_{i=1}^{M}\sum_{k=1}^{N} R_i^*(u,v)T_k(u,v)\times e^{-ju(x_i+x_k)+jv(y_i-y_k)} \\ &+\sum_{i=1}^{M}\sum_{l=1}^{M} R_i^*(u,v)R_l(u,v)\times e^{-ju(x_i-x_l)+jv(y_i-y_l)} \\ &+\sum_{k=1}^{N}\sum_{l=1}^{N} T_k(u,v)T_l^*(u,v)\times e^{-ju(x_k-x_l)-jv(y_k-y_l)} \\ &+\sum_{k=1}^{M}\sum_{l=1}^{N} T_k^*(u,v)T_l(u,v)\times e^{ju(x_k-x_l)+jv(y_k-y_l)}\end{aligned} \tag{3}$$

where the superscript * indicates a complex-conjugate operation, $i \neq l$ and $k \neq l$. The JPS is then inverse Fourier transformed again to yield

$$f_c(x,y)=\sum_{q=1}^{8} f_{cq}(x,y)$$

$$f_{c1}(x,y)=\sum_{i=1}^{M} r_i(x,y)\otimes r_i^*(x,y)$$

$$f_{c2}(x,y)=\sum_{k=1}^{N} t_k(x,y)\otimes t_k^*(x,y)$$

$$f_{c3}(x,y)=(\lambda f_l)^2\sum_{i=1}^{M}\sum_{k=1}^{N} r_i(x-x_i-x_k, y+y_i-y_k) \otimes t_k^*(x-x_i-x_k, y+y_i-y_k)$$

$$f_{c4}(x,y)=(\lambda f_l)^2\sum_{i=1}^{M}\sum_{k=1}^{N} r_i^*(x+x_i+x_k, y-y_i+y_k) \otimes t_k(x+x_i+x_k, y-y_i+y_k)$$

$$f_{c5}(x,y)=(\lambda f_l)^2\sum_{i=1}^{M}\sum_{l=1}^{M} r_i(x-x_i+x_l, y+y_i-y_l) \otimes r_l^*(x-x_i+x_l, y+y_i-y_l)$$

$$f_{c6}(x,y)=(\lambda f_l)^2\sum_{i=1}^{M}\sum_{l=1}^{M} r_i^*(x+x_i-x_l, y-y_i+y_l) \otimes r_l(x+x_i-x_l, y-y_i+y_l)$$

$$f_{c7}(x,y)=(\lambda f_l)^2\sum_{k=1}^{N}\sum_{l=1}^{N} t_k(x+x_k-x_l, y+y_k-y_l) \otimes t_l^*(x+x_k-x_l, y+y_k-y_l)$$

$$f_{c8}(x,y)=(\lambda f_l)^2\sum_{k=1}^{N}\sum_{l=1}^{N} t_k^*(x-x_k+x_l, y-y_k+y_l) \otimes t_l(x-x_k+x_l, y-y_k+y_l), \tag{4}$$

where $\otimes$ is a correlation operation, f_l is a focal length of lens $L_1(L_2)$

and λ is the wavelength of the collimating light[(2)].

3. Discrimination Algorithm for Correlation Decision

In general, experimentations show that the cross correlation peak may be equal to the corresponding autocorrelation even if no good match occurs. For example, if one takes a white square shape jointly correlated with a triangle one, then the cross correlation peak produces the same result as the autocorrelation peak of the triangle (see Fig. (2)). The ratio of the autocorrelation to the cross correlation peak height is the method that has been used for correlating deterministic shapes, such as character recognition (See Ref. [8]). Recently, Zhang and Karim [9] have used the ratio of the cross correlation to the target autocorrelation peak height to determine the correlation result. This method may cause a match declaration even if a mismatch is required, especially when the target values are lower than the reference one. For example, the autocorrelation height of the square is (64) and that of the triangle is (36). The cross correlation is also equal to (36). If the triangle shape represents the input object, and the square shape corresponds to the reference, then this method will declare a match. This means that the final discrimination result must depend on three correlation peaks to make a correct decision:

$$VR_i = VT_k = VC_{i,k} \qquad (5)$$

where VR_i, VT_k are the autocorrelation peak values of the i'th reference and k'th target, respectively, and $VC_{i,k}$ is the cross correlation peak value.

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(2) Equation (4) is different from Eq.(4) of Ref.[7] where the derivation in this paper leads to additional terms namely, $f_{c6}(x,y)$ and $f_{c8}(x,y)$.

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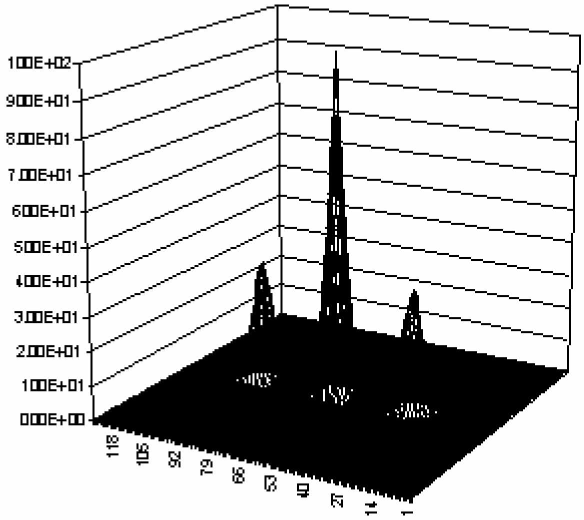
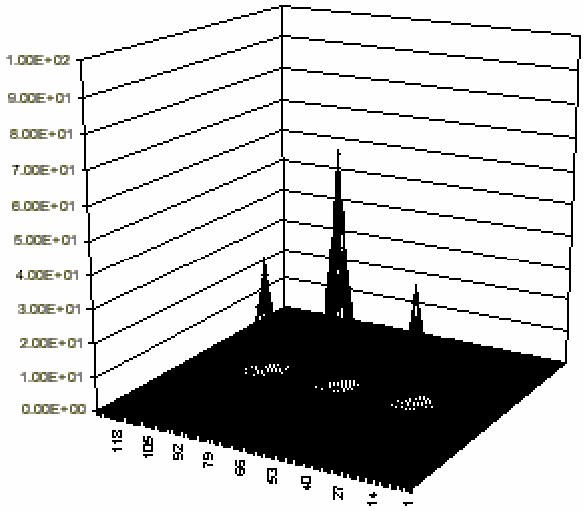
(a)

(b)



(c)



(d)

Fig.(2): (a) Input plane with square shape as the reference and triangle shape as the target, (b) Input plane with triangle shapes as the reference and the target, (c) Correlation output corresponding to (a), (d) Correlation output corresponding to (b).

As evident from Eq.(5), three correlation peaks are needed to make a correct decision of correlation. These peaks must be obtained at the output plane. In the case of one reference and one input object, and assuming *VR* is stored previously, then *VT* can be obtained from the zero-order peak while *VC* already exists at it suitable position. But, for multi-object as planed, there is a large interference between the cross correlation peaks and there is a strong zero-order peak in the correlation output. This is the main problem facing the conventional JTC.

Here we propose a new discrimination algorithm for correlation decision which can be stated as follows:

According to the Eq. (5), the algorithm required for making decision of the correlation result is shown in Fig. (3). This algorithm can be processed after sending the correlation output to an on line computer as on line. The algorithm will declare that the objects are correlated if and only if :

$$\frac{VR_i}{VC_{i,k}} = 1 \quad \text{and} \quad \frac{VT_k}{VC_{i,k}} = 1 \qquad (6)$$

The value of reference autocorrelation (VR) is stored previously and the target autocorrelation can be obtained according to

$$VT = Z - VR \qquad (7)$$

where Z is the value of the zero-order correlation peak.

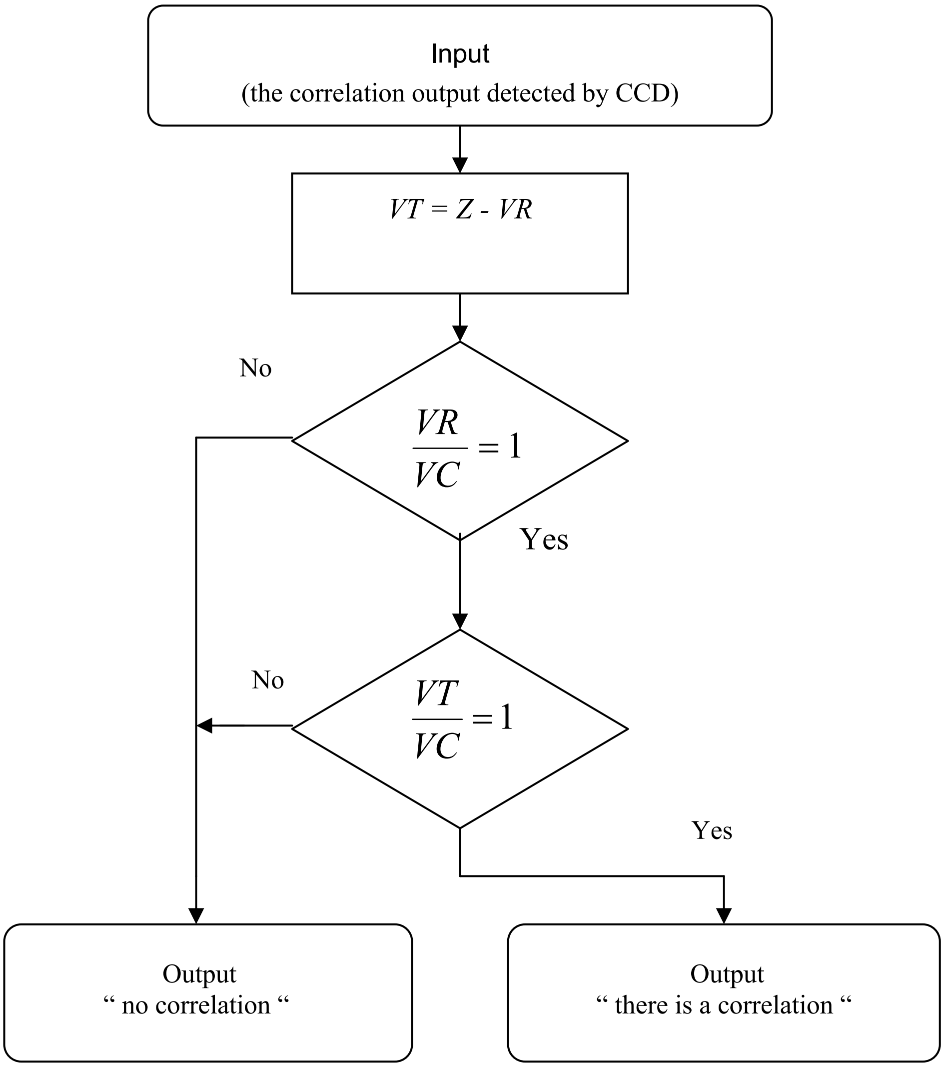


Fig. (3): An algorithm for making the discrimination decision.

4. Simulation Results for conventional JTC

4.1 Input Joint Image with Multi-Reference and Single-Target

In this case, six terms will be produced in the output plane. These terms represent the zero-order peak, the cross correlations between the target and each of the references, and unwanted cross correlation between the different reference scene objects. To eliminate the unwanted terms from the correlation plane, an image subtraction technique is used [5]. Here, we used the correlation subtraction scheme to simplify the design of the new JTC architecture. In this technique, firstly, the correlation output $C_j(x,y)$ is obtained by displaying both the reference and the input scene in the input plane. Then, the correlation output $C_r(x,y)$ of the reference image is computed by displaying the reference image only. The final correlation output $C_o(x,y)$ is obtained by subtracting $C_r(x,y)$ from $C_j(x,y)$, i.e.,

$$C_o(x,y) = C_j(x,y) - C_r(x,y) \qquad (8)$$

This technique is depicted in Fig. (4). Thus, the new system will subtract the references autocorrelation term from the zero-order peak. In addition, all the cross correlations between the references will be reduced (see Fig. (5)). Accordingly, the value of the target autocorrelation can be obtained directly; it is represented by the value of the central zero-order peak, i.e.

$$VT = Z .$$

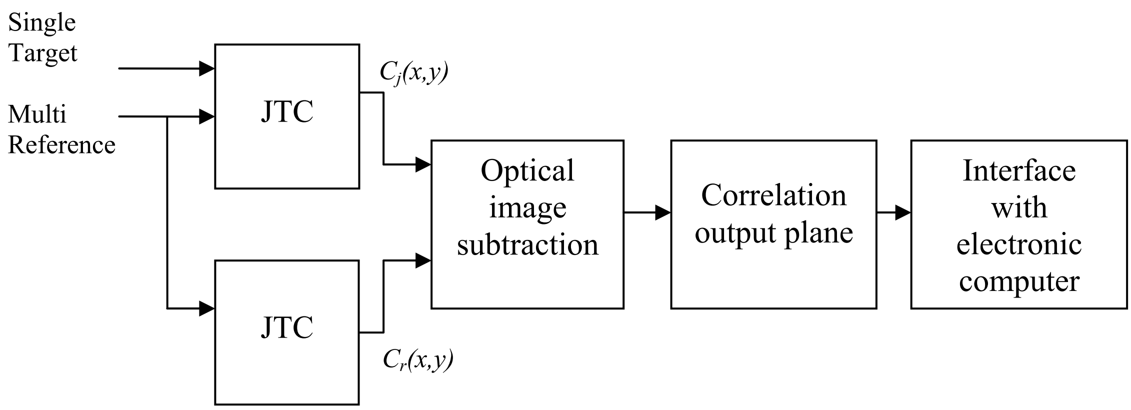
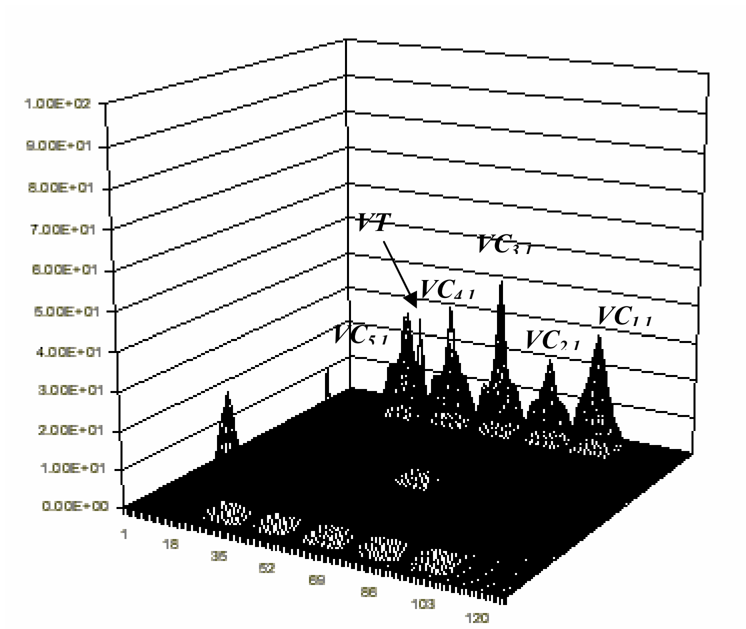


Fig. (4): Joint Transform Correlator architecture using image subtraction technique.

(a)



(b)

Fig.(5): Five references and a single-target, (a) Input plane, (b) Correlation output plane using conventional JTC.

4.2 Input Joint Image with Multi-Reference and Multi-Target

In multi-target state, a new problem will be occurred beside the aforementioned ones. This problem is "How the value of each target autocorrelation can be obtained?". Here, to solve the target autocorrelation problem, a new JTC system is proposed, and it is called a double joint transform correlator (DJTC).

5. New JTC architectures

5.1 Double JTC System

Figure (6) depicts the proposed DJTC block diagram. There are two conventional JTCs operated simultaneously. The reference and the target objects are jointly combined in the input plane of the first one. Thereby, this JTC is used to obtain the cross correlations between the reference and target objects and it will be called the main JTC (MJTC). The other JTC is used to produce the autocorrelation of each target. Whereby, the input scene is displayed side by side with the support reference (SR) at the input plane of it. The SR represents a square object, which has the same size of other objects. As evident from section (3), the cross correlation between each object and such reference will be equivalent to the autocorrelation of this object. Accordingly, the cross correlations found between the SR and other targets represent the autocorrelations of these targets. Therefore, the second JTC is called the support JTC (SJTC).

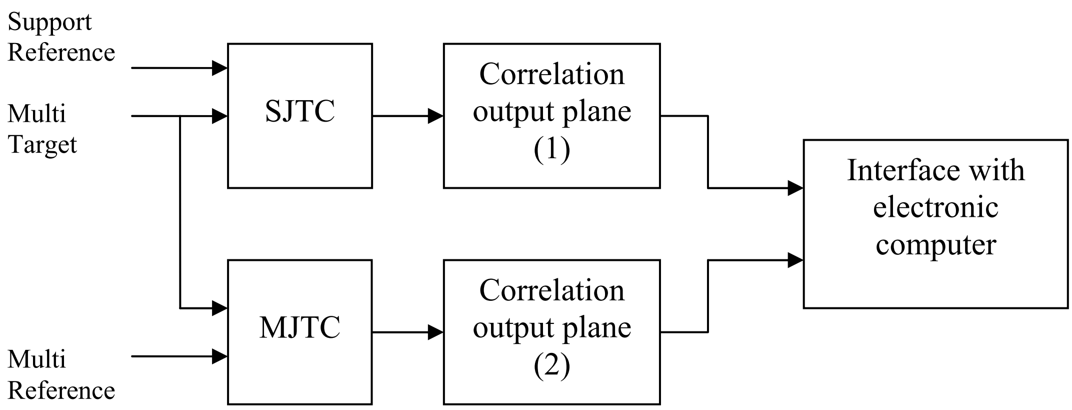


Fig. (6): Schematic diagram of the proposed Double JTC technique.

It is evident that the same problems aforementioned in Sec.(4.1) are presented here. The SJTC correlation output consists of a pair of autocorrelation peaks corresponding to each target in the input scene, a zero-order peak which becomes stronger by increasing the number of target objects, and the cross correlation peaks between the target objects. Also, the MJTC is suffered from false alarms. The correlation output of the MJTC contains the cross correlations between the reference objects, the cross correlations between the target objects, and the autocorrelation peaks of each the reference and target objects which form a strong zero-order peak. The occurrence of these terms is found to complicate the detection operation of the all desired peaks; similar remarks are associated with the correlation output of the SJTC; target autocorrelation peaks from the SJTC output plane and the cross correlation between the reference and the target objects from the MJTC output plane. Thus, to overcome the all above problems, the proposed Fourier plane image subtraction operation will be used to eliminate the unwanted correlation terms. Notice that the subtraction operation can be performed either optically or electronically using the electronic computer [10,11].

As illustrative example, consider the input plane shown in Fig. (7.a). Figures (7.b) and (7.c) represent the correlation output of the MJTC and SJTC, respectively, for the double JTC after the subtraction. The two correlation outputs are used as input data to the algorithm described by Eq. (6) to detect the targets. Here, the data of the algorithm is illustrated in Table (1), Table (2) and Table (3).

Table (1): Cross correlation height values ($VC_{i,k}$) of Fig.(7.b).

i \ *k*	***1***	***2***	***3***	***4***	***5***	***6***
1	30	19	25	32	36*	22
2	34	22	30	31	24	16
3	21	28*	21	28	19	16

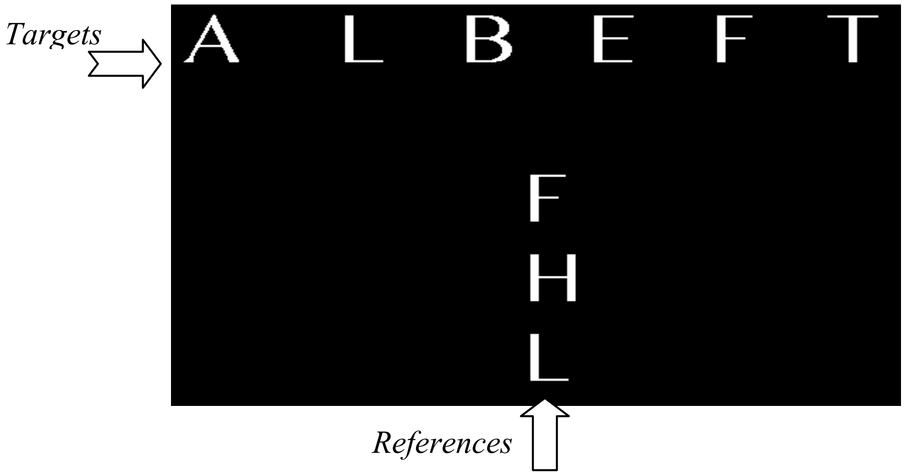
Table(2): Autocorrelation height values (VT_k) of Fig.(7.c).

k	***Level of peak of target Autocorrelation***
1	42
2	28*
3	32
4	48
5	36*
6	28

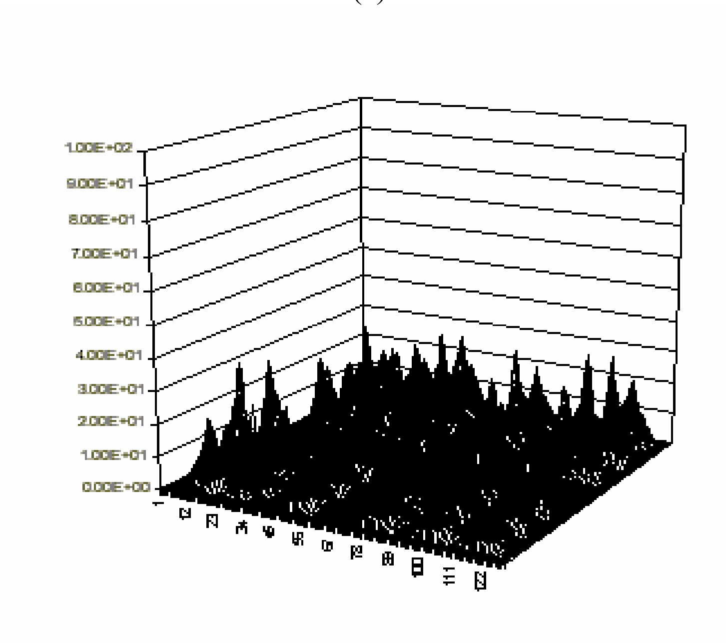
Table(3): Autocorrelation height values (VR_i) stored previously.

i	***Level of peak of reference Autocorrelation***
1	36*
2	40
3	28*

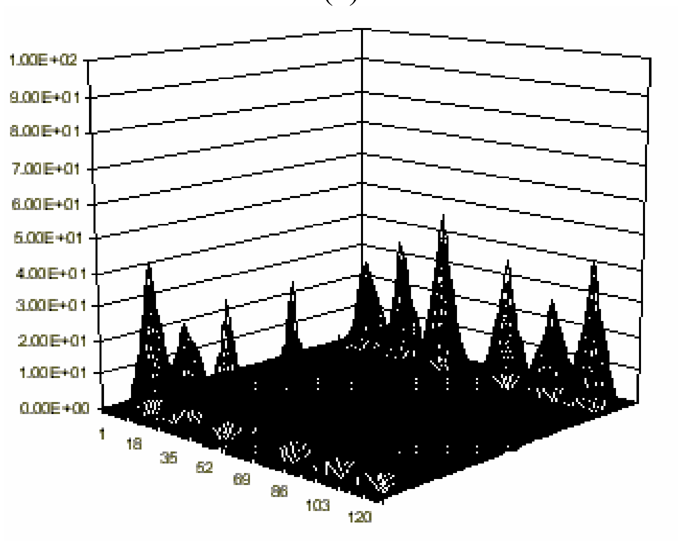
where * means the correlation state.



(a)



(b)



(c)

Fig.(7): Double JTC technique, (a) Input plane, (b) MJTC output plane after subtraction, (c) SJTC output plane after subtraction.

5.2 Normalized DJTC Technique

This technique is depicted schematically in Fig. (8) and uses two identical optical threshold circuits (OTCs). The OTC offers an optical logic operation and can be obtained by using (SLM) devices. This operation can be expressed as

$$FM_o(x,y) = \begin{cases} CM_o(x,y) & \text{if } M_o(x,y) \geq T \\ 0 & otherwise, \end{cases} \quad (9)$$

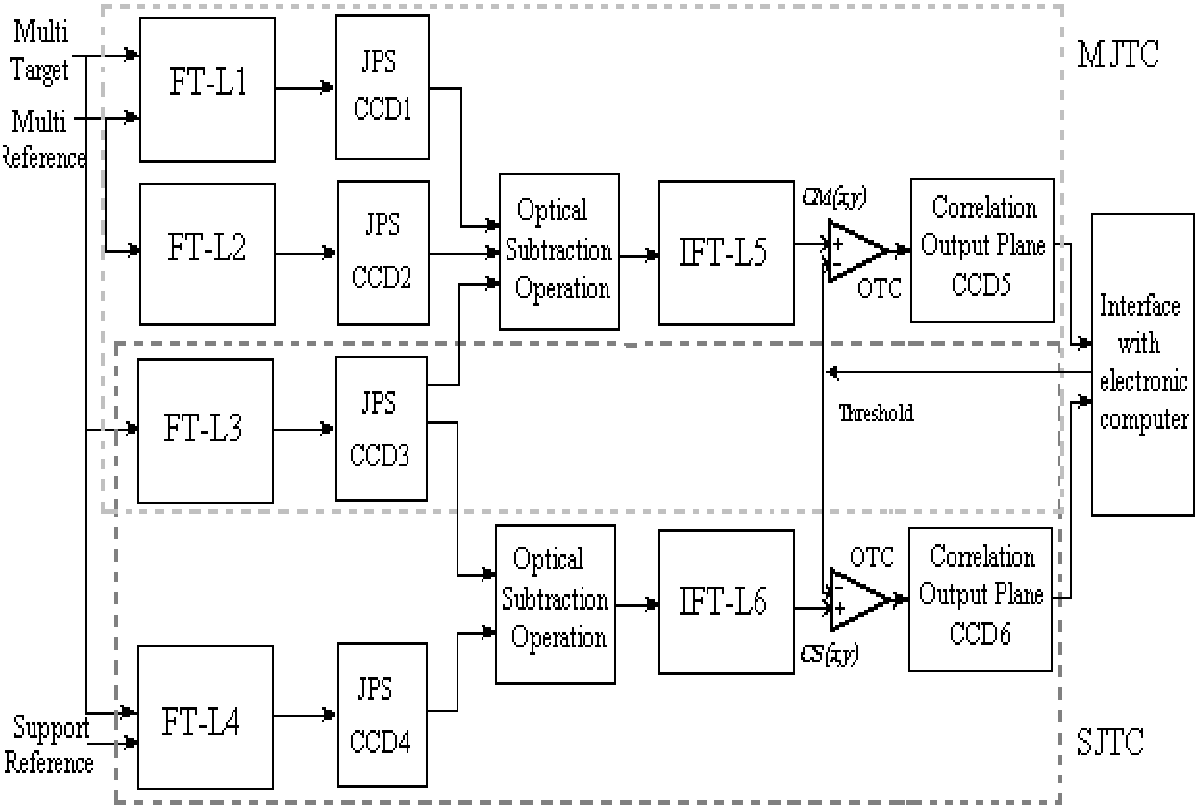
where $FM_o(x,y)$ represents the final correlation output of the MJTC part. $CM_o(x,y)$ is the output of inverse Fourier transform lens L5 of MJTC and T is the threshold value which is related to the smallest value among the autocorrelations of the references "*SVR*" by

$$T = SVR - 1 \quad (10)$$

.

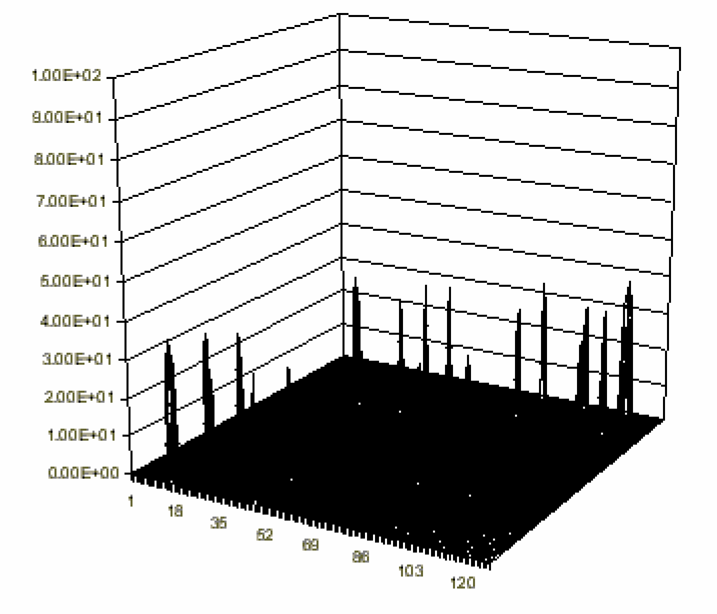
The threshold level of the OTC can be obtained by the electronic computer. This will not cause any effect on the speed of the system because it will be computed and saved on it earlier. Also, the same threshold is used in the other OTC to reduce the correlation bandwidth problem in the SJTC part.

Figure (9) illustrates the effect of the normalization at the correlation output of Fig. (7). As evident, the normalized DJTC technique introduces sharper cross correlations and autocorrelations in the MJTC and SJTC output planes, respectively; without any effect of peaks heights. Also, some of the correlation peaks that indicate no match will be reduced here. In the new technique, the detection of the correlation peaks is more efficient and more accurate compared with other technique. .

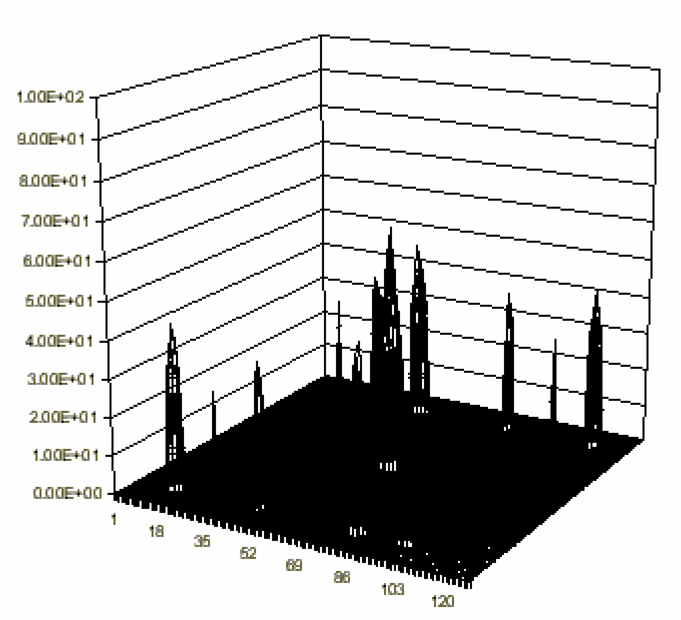


Notes: (FT-L1) means Fourier transform using lens L1.
(IFT-L5) means inverse Fourier transform using lens L5.
(OTC) means optical threshold circuit.

Fig. (8) : Architecture of the proposed Normalized DJTC.



(a)



(b)

Fig. (9): Normalized DJTC correlation output corresponding to Fig. (7.a), (a) MJTC correlation output plane, (b) SJTC correlation output plane.

7. Conclusions

We have investigated the main features of using conventional joint transform correlation (JTC) technique for optical pattern recognition. The correlation plane of the JTC has many terms whose positions, numbers and heights depend, respectively, on the locations, numbers and shapes of the input and reference objects. A new method has been introduced to improve the correlation discrimination results. Generally, this method can be used for recognizing different shapes. The simulation results indicate that the conventional JTC are characterized by large sidelobes, interference between correlation peaks, and strong zero-order peak at the output correlation plane.

In this paper, conventional JTC has been used to correlate multi-reference and single or multi-target in one step. The double JTC (DJTC) is a new architecture which has been proposed to find the autocorrelations of the target objects, and the cross correlations between the targets and references images. To reduce the unwanted correlation terms, DJTC has been modified using Fourier plane image subtraction technique. The modified DJTC technique has been found to be suffered from the problem of large bandwidth correlation peaks.

The normalized double JTC (NDJTC) has been presented. to yield significantly better correlation output than the double JTC. The optical threshold circuits (OTCs) have been used to obtain sharper correlation peaks for free input scenes.

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