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Soon, Boon Yi; Karim, Mohammad A.; Hardie, Russell C.; and Alam, Mohammad S., "Joint Wavelet Transform Correlation with Separated Target and Reference Planes" (1998). Electrical and Computer Engineering Faculty Publications. 58.  
https://ecommons.udayton.edu/ece_fac_pub/58

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Joint wavelet transform correlation with separated target and reference planes

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Abstract: In recent years, we realize the usefulness of feature extraction for optical correlator and hereby, we investigate the capability of Laplace operator in feature extraction of multiple targets. The first-order terms and the false alarm terms in the correlation output would be removed using electronic power spectrum subtraction technique. Most importantly, the entire magneto-optic SLM is completely utilized for displaying only targets in the input scene. A new cost efficient hardware implementation is proposed and aforementioned result of the proposed system is evaluated through computer simulation.

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OCIS codes: (100.5010) Pattern recognition and feature extraction; (100.4550) Optical correlators

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1. Introduction

The optical correlator evolves through two main structures; the joint transform correlator (JTC) by Weaver and Goodman and the VanderLugt’s correlator by VanderLugt [1,2]. The joint transform correlator gains popularity since the joint transform correlator relaxes the stringent optics alignment that is required by the VanderLugt’s correlator. The joint transform correlator has gone through many improvements [3] and has proved its usefulness in pattern recognition, feature extraction and target detection. The correlation output is enhanced using the binary joint transform correlator which distinguishes the crosscorrelation terms from the autocorrelation terms [4-6]. Further progress is made by introducing various types of filters in the Fourier plane of the JTC system to discriminate the autocorrelation terms and increase the peak intensity of the crosscorrelation output [7-10]. The wavelet transform is found successful when implemented together with the joint transform correlator [11-14], and the joint wavelet transform correlator works especially well for feature extraction. Since the edge information is embedded in the high frequency content in the images, preprocessed images with wavelets are equivalent to high pass or band pass filtering the target object. This would tremendously improve the proficiency of the correlation output for feature extraction [15]. However, the first-order terms still exist in the correlation output plane.

Subtracting the target-only and reference-only power spectrums from the joint power spectrum could solve this problem [16,17]. However, using the power spectrum subtraction method, a few more steps would be required to obtain the desired cross-correlation output for the Robert and Sobel operators which have two versions each to detect edges in relatively orthogonal direction [12,13]. Therefore, if we could use a single operator such as the Laplace operator to accomplish the same task, we would reduce the number of steps required. Over the years, many improvements in the JTC system are made feasible with the availability of the high quality optics equipment like the magneto-optic SLM, liquid crystal light valve, CCD camera and etc. The SLM is usually the most expensive equipment in the correlator system. Conventionally, we would divide the input scene into two halves; one half for the target objects and the
other half for the reference object. We proposed to utilize the SLM fully for displaying target-only objects without sacrificing any space for the reference-only object. In the correlation output plane, we would remove both the first-order and the false alarm terms using the power spectrum subtraction technique. This technique is more superior to the chirp-encoded joint transform correlator [18], which requires more equipment and precise optic alignment. After the subtraction, we could rotate a half cycle along both x-axis and y-axis, and superimpose the pair of correlators to obtain a single stronger correlation peak.

2. Theory

The optical correlator needs to be both cost effective and simple to implement too. We proposed a single SLM system shown in Fig. 1.

![Fig. 1. The single SLM correlator architecture.](image)

First, the laser beam is beam splitted by the beam splitter, BS 1. The transmitted beam will be expanded by the spatial filter assembly, SFA 1 and collimated with the lens 1, which is placed a focal length away from the pin hole of the spatial filter assembly. The shutter controls the passage of the reflected beam from the BS 1, which is monitored by the switching circuitry to control the sequence of operations. The mirrors, M 1 and M 2 will reflect this beam before it is expanded by SFA 2 and collimated using lens 2. The transmitted beam will map the targets image displays by the magneto-optic SLM into its Fourier transform with the Fourier transform lens, lens 3 placed a focal length after the SLM. Note that this happens when the shutter is closed. When the shutter is opened, the reflected beam will superimpose the reference image, which is displayed on the transparency, with the targets image using the BS 2. The corresponding Fourier transform of the joint input scene is obtained a focal length after the Fourier transform lens, which would be captured by the CCD camera. The switching circuitry monitors the overall sequence of the system.

The joint input scene can be described as the given,

\[
f(x, y) = \sum_{i=1}^{4} t_i(x-x_i, y-y_i) + r(x-x_0, y+y_0),\tag{1}
\]

where the first term represents the four targets and the second term is the Laplace operator that we will use as the reference object. Also, the x, y, x_0, y_0, x_i, and y_i are
the spatial domain variables. The lens 3 will give the Fourier transform of the images that is projected by the collimated beam at a focal length away. The result of the Fourier transform is given by

$$F(u, v) = \sum_{i=1}^{4} T_i(u, v)e^{j2\pi(-ux_i-vy_i)} + R(u, v)e^{j2\pi(-ux_0-vy_0)},$$

(2)

where the first and the second terms are the Fourier transform of the targets and the reference, respectively. Also, $u$ and $v$ are the Fourier domain variables. The corresponding joint power spectrum captured with the CCD camera is given as

$$|F(u, v)|^2 = |R(u, v)|^2 + \sum_{i=1}^{4} |T_i(u, v)|^2$$

$$+ 2 \sum_{i=1}^{4} |R(u, v)||T_i(u, v)||cos[\phi_{ti} - \phi_r + j2\pi(u(x_i + x_0) + v(y_i - y_0))]|$$

$$+ 2 \sum_{i=1}^{4} \sum_{k=1}^{4} |T_i(u, v)||T_k(u, v)||cos[\phi_{ti} - \phi_{tk} + j2\pi(u(x_i + x_k) + v(y_i - y_k))]|,$$

(3)

where the first two terms are the first-order terms, the third terms represents the desired crosscorrelation terms, and the last term represents the false alarm terms. Also, the $\phi_{ti}$, $\phi_{rk}$, and $\phi_r$ are the phase factors of the targets and the reference, respectively, and the $x_k$ and $y_k$ are the spatial domain variables. When the shutter is closed, the targets-only power spectrum is recorded and described by

$$|F_T(u, v)|^2 = \sum_{i=1}^{4} |T_i(u, v)|^2$$

$$+ 2 \sum_{i=1}^{4} \sum_{k=1}^{4} |T_i(u, v)||T_k(u, v)||cos[\phi_{ti} - \phi_{tk} + j2\pi(u(x_i + x_k) + v(y_i - y_k))]|,$$

(4)

which has all the first-order terms and all the false alarm terms except $|R(u, v)|^2$. The reference-only power spectrum is known in regard to the Laplace operator used, and is precalculated and stored in the computer for further computation. It is given by

$$|F_R(u, v)|^2 = |R(u, v)|^2.$$  

(5)

Using the electronic power spectrum subtraction technique, we obtained the modified power spectrum, which is given as

$$|M(u, v)|^2 = |F(u, v)|^2 - |F_T(u, v)|^2 - |F_R(u, v)|^2$$

$$= 2 \sum_{i=1}^{4} |R(u, v)||T_i(u, v)||cos[\phi_{ti} - \phi_r + j2\pi(u(x_i + x_0) + v(y_i - y_0))]|.$$  

(6)

The modified power spectrum would then be display on the magneto-optic SLM and its approximately equivalent inverse Fourier transform will be performed with the lens
3. Note that in the correlator output, there would be four pairs crosscorrelation terms, a pair of crosscorrelation peaks for each target. If one of the crosscorrelation output of each target is rotated about the x-axis and the y-axis, and superimposes with the rest, we would obtain a single set correlator output with twice its original intensity.

The single operator that we would investigate here is the Laplace operator, which is described as

\[
\begin{bmatrix}
1 & 1 & 1 \\
1 & -8 & 1 \\
1 & 1 & 1 \\
\end{bmatrix}.
\] (7)

The reason why the Laplace operator is chosen as the single wavelet is that it has a good high frequency profile in the power spectrum that is shown in Fig. 2.

Fig. 2. The power spectrum of the Laplace operator.

Note that the pass band is at all four corners; passing the high frequency content in all four orthogonal directions. In the joint input scene, the position of the Laplace operator determined the amount of spatial separation between the target and reference which determine how far the pair of correlators for each target is separated in the correlator output plane. Therefore, the Laplace operator should be placed in the farthest possible distance in the joint input scene to avoid the pair of the correlators from overlapping. The farthest possible distance is any of the four corners in the input scene.

3. Computer simulation results

Next, we would analyze the performance of the Laplace operator in feature extraction with a simple joint image, which is shown in Fig. 3. The cartoon images are Superman, Lois Lane, Professor Hamilton, and Supergirl, which are the four targets; each image is 135x120 in size. While the shutter is opened, the reference-only scene is superimposed with the targets-only scene to obtain the joint input scene. The position of the Laplace operator is planted at the bottom right-hand corner near to the Supergirl and could not be seen due to its relative size. The joint power spectrum is recorded by the CCD camera and stored to the computer as described in Eq. 3. Now, the shutter is closed and the targets-only power spectrum is recorded to computer as illustrated in Eq. 4. The computer would begin to perform the power spectrum subtraction to obtain the modified power spectrum that is given in Eq. 6. Note that the reference-only power spectrum is already known and no additional step is required to capture its power spectrum like the joint and targets-only power spectrums. This result is then displayed on...
the magneto-optic SLM and the inverse Fourier transform operation is performed. The corresponding correlator output obtained is captured with the CCD camera and stored to the computer. Note that in the four targets and one reference scenario, there would be four pairs of crosscorrelation peak, one for each target. In an ordinary Joint Transform Correlator, the crosscorrelation output appears as the intensity peak, while in the Joint Wavelet Transform Correlator, the crosscorrelation output appears as the feature extraction of the targets. The correlator output is shown in Fig. 4.

![Fig. 3. The joint input scene of the four cartoon images and the Laplace operator.](image1)

![Fig. 4. The correlator output of the four cartoon images.](image2)

We could see that the four of the crosscorrelation terms are at the top left corner while the other four are at the bottom right corner. With close examination, we observed the
The top left and bottom right crosscorrelation output are identical, if either of them are rotated in both axes and superimpose with the other, the crosscorrelation intensity would be double. Electronically, the computer performs the rotation and the superposition operations. The double crosscorrelation intensity output is shown in Fig. 5.

![Fig. 5. The rotated and superimposed crosscorrelation output of the four cartoon images.](image)

The Laplace operator performs feature extraction as well as the other operators; e.g. Roberts, Sobel, and etc. The Laplace operation has a second order derivative effect and is best utilized for its zero-crossings to detect the edge location [19]. Notice that the edges detected are pretty thick because of the second order derivative effect. Conversely, Roberts operator has the first order derivative effect and gives thinner edge. However, Roberts has two versions which detect edges in the 35 and the 135 degrees directions respectively. Therefore, more steps are required in the computing the crosscorrelation as compared to the Laplace operator. If only one version of the Roberts operator is used, the corner information will not be clearly detected. This is because the corner information can be represented by its x- and y-components, and either of the Roberts version is good in detecting either the x- or the y-component but not both. The Laplace operator would not have this problem because it has strong power spectrum profile in the corner directions as shown in Fig. 2. Based on the correlation output of the cartoon images, we verified that the Laplace operator could be a good feature extraction operator with its high pass filtering capability.

4. Conclusion

A single SLM architecture that we proposed cut the cost of the hardware implementation. Most importantly, we are now able to fully utilize the magneto-optic SLM to its maximum capacity in displaying the targets-only images. As the Laplace operator is a single version operator, its allows us to cut down the number of computation steps and speed up the correlation process. The result of the single correlation output enables the correlator output pair to be superimposed and doubled its intensity. The features extracted for the four cartoon images give comparable result to that of the Sobel and the Robert operators’.