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CLUTTER EFFECTS ON OPTICAL CORRELATORS

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13. ABSTRACT (Maximum 200 words)
We examine the effect of varying ground clutter on the performance of optical correlators. We compare the classical matched (CMF), phase-only (POF), and binary phase-only (BPOF) filters. A new definition of the signal-to-clutter ratio (SCR) in the input scene and the signal-to-noise ratio (SNR) in the correlation plane is presented. Simulations show the POF and BPOF always outperform the CMF. The BPOF performs best in scenes with low SCR ratios (high clutter) using the new metric. The POF performs best for all levels of SCR when a block is placed in the filter plane.

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1. INTRODUCTION

Since the development of the Vander Lugt optical correlator[1], the concept of coherent optical processing for pattern recognition has been intensely explored. The proposal of the POF[2] and BPOF[3] has sparked interest in using these filters in optical processing because of their high Horner efficiency and increased SNR.[4] The BPOF has been particularly interesting because it can be implemented on current state-of-the-art spatial light modulators with comparatively little loss in SNR.[5] This knowledge has led many researchers to investigate

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[1] Vander Lugt, A. (1964) Signal detection by complex spatial filtering, *IEEE Trans. Inf. Theory*, **IT-10**:139.

[2] Horner, J.L. and Gianino, P.D. (1984) Phase-only matched filtering, *Appl. Opt.*, **23**:812.

[3] Horner, J.L. and Leger, J.R. (1985) Pattern recognition with binary phase-only filters, *Appl. Opt.*, **24**:609.

[4] Horner, J.L. and Bartelt, H.O. (1985) Two-bit correlation, *Appl. Opt.*, **24**:2889.

[5] Psaltis, Dominic, Paek, Eung G., and Venkatesh, Santosh, S. (1984) Optical image correlation with a binary spatial light modulator, *Opt. Eng.*, **23**:698.

methods of optimizing BPOF performance relative to some figure of merit such as SNR.[6,7,8,9] We have noticed that the majority of imagery used to benchmark most laboratory demonstrations and computer simulations of optical correlation systems is binary in nature. This imagery is sufficient in exploring the basic parameters of a given system, but does not test the system's ability to identify a given pattern in cluttered or noisy background environments. Results of recent computer simulations using 2-D grey scale images have led us to investigate the performance of the CMF, POF, and BPOF where the background noise level of an input scene varies. Figure 1 shows an example of the results that prompted this study. The correlations in Figure 1 were made from filters derived from the segmented tank placed in a 128 x 128 zero filled array. Note that the correlation peak from the CMF is buried in the noise where the POF and BPOF peak are clearly evident.

A new definition for the SCR of the input scene and SNR of the correlation plane is used to take advantage of the statistical nature of the noise and assess the results. We propose this simple metric in the hope that other filter researchers can use it compared to results with some common objectivity.

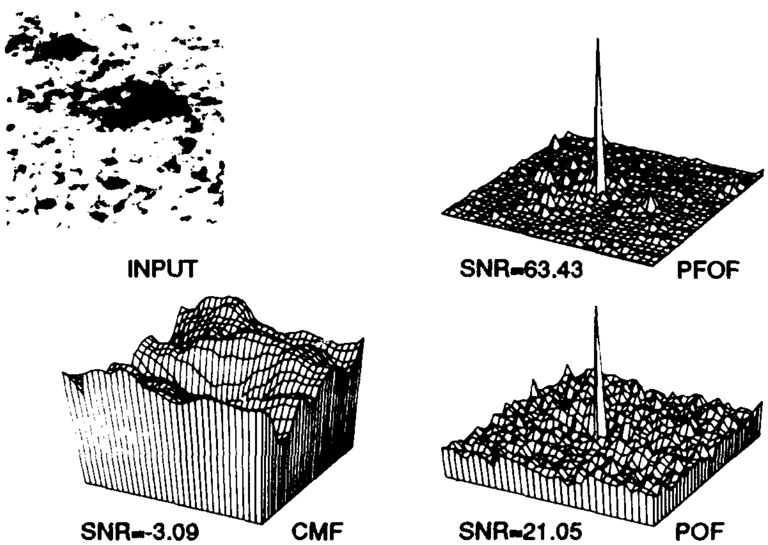

Figure 1. Correlations With the CMF, BPOF, and POF. The filter template is made from the segmented tank.

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6 Bartelt, H. and Horner, J. (1985) Improving binary correlation filters using iterative techniques, *Appl. Opt.*, **24**:2894.

7 Kallman, R. (1986) Optimal low noise phase-only and binary phase-only correlation filters, *Appl. Opt.*, **25**:4216.

8 Farn, M.W. and Goodman, J.W. (1988) Optimal binary phase-only matched filters, *Appl. Opt.*, **27**:4431.

9 Flannery, David L., Loomis, John S., and Milkovich, Mary E. (1988) Design elements of binary phase-only correlation filters, *Appl. Opt.*, **27**:4231.

2. FILTER MODELS

The classical matched filter for a signal h(x) is defined as $H(\upsilon)$. In polar form we can represent it as

$$H(\upsilon) = |H(\upsilon)| \exp^{(-j\phi(\upsilon))}. \tag{1}$$

The phase-only filter is derived from the CMF by dividing by the amplitude, effectively setting the amplitude everywhere equal to 1. This results in

$$H_{\phi}(\upsilon) \exp^{(-j\phi(\upsilon))}. \tag{2}$$

We simplify further to create the BPOF by binarizing the continuous phase-only function $\phi(\upsilon)$ to yield

$$H_{BI}(\upsilon) = \begin{cases} +1 & \text{if} \quad \phi \geq 0, \\ -1 & \text{if} \quad \phi < 0. \end{cases} \tag{3}$$

We do not attempt any optimization techniques on the BPOF for this study.

The signal-to-clutter ratio (SCR) at the input and signal-to-noise ratio of the correlation are given by a new metric based on the standard deviation of the undesired information in each plane. The SCR of the input scene is given by

$$SCR = \frac{Object_{ave}}{\sigma_{clutter}} \tag{4}$$

which is the average of the object pixels divided by the standard deviation of the clutter (background pixels). Similarly, the SNR in the correlation plane is given by

$$SNR = \frac{P_c - Noise_{ave}}{\sigma_{noise}}. \tag{5}$$

Here, P_c represents the correlation peak, $Noise_{ave}$ is the average noise in the correlation plane, and σ_{noise} is the standard deviation of the noise in the correlation plane. Note, we subtract off the average noise, $Noise_{ave}$ in the numerator to be consistent with σ_{noise} in the denominator, where the average value has also been subtracted out and is given by

$$\sigma_{noise} = \left(\frac{\sum_{n=1}^{N} (Noise_n - Noise_{ave})^2}{N} \right)^{\frac{1}{2}} . \qquad (6)$$

3. SIMULATION

The input scenes used in this study are 128 x 128 and 256 x 256 imagery of tanks, trucks, and armored personnel carriers in a desert environment with a 256-level greyscale. The correlations and subsequent processing of the SCR and SNR are implemented on a VAX 8650 using the Interactive Data Language.[10]

The filters are made from segmented scene objects placed in a 128 x 128 or 256 x 256 zero-filled array. The background noise level of the input scene is varied by multiplying the background pixels by a constant, K, ranging from 0.1 to 1.5 in 0.1 increments. The object pixels are not changed. This can be represented as

$$Input = O + KN_c \qquad (7)$$

Here, O is the object and N_c is the background noise clutter. The SCR and SNR for the CMF, POF, and BPOF are calculated and plotted for the range of K values presented in amplitude. In addition to this simulation, we study the effect on SNR vs SCR of different sized DC blocks placed in the filter plane.

[10] IDL, Interactive Data Language, Research Systems, Inc., 2021 Albion Street, Denver, Colorado 90207.

4. RESULTS

4.1 Initial Simulations

The input scene in Figure 1 is a 128 x 128 array with a single tank which is the object. Simulations with two other 128 x 128 array scenes yielded similar results which will not be discussed for brevity. A 256 x 256 array scene containing multiple objects was also used in this simulation.

We chose to test a multiple object scene to study the effect of noise signals that are not unlike that of the target object. The multiple object scene, CMF, POF, and BPOF correlations using the armored personnel carrier (APC) as the object are shown in Figure 2.

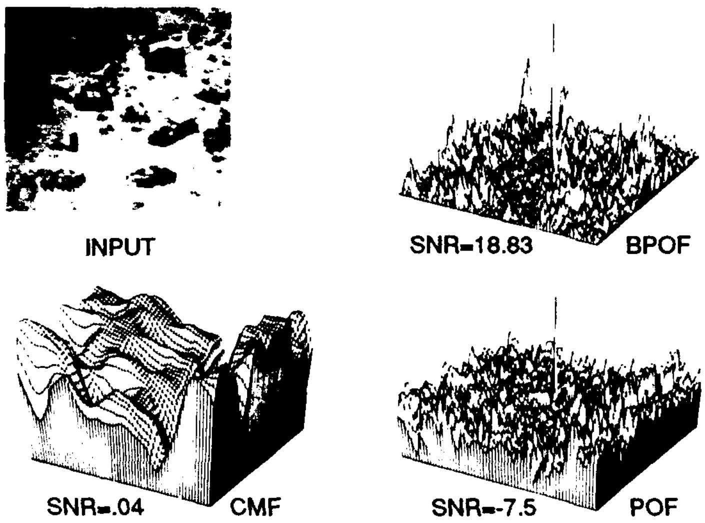

Figure 2. Correlation with the Multiple Object Scene. The template is made from the APC in a zero array.

The multiplicative background factor, K is 1.0 (original scene) for the correlations shown in Figure 2. The calculated output signal-to-noise vs input signal-to-clutter ratio for the single and multiple object scene for the entire range of K values is shown in Figure 3.

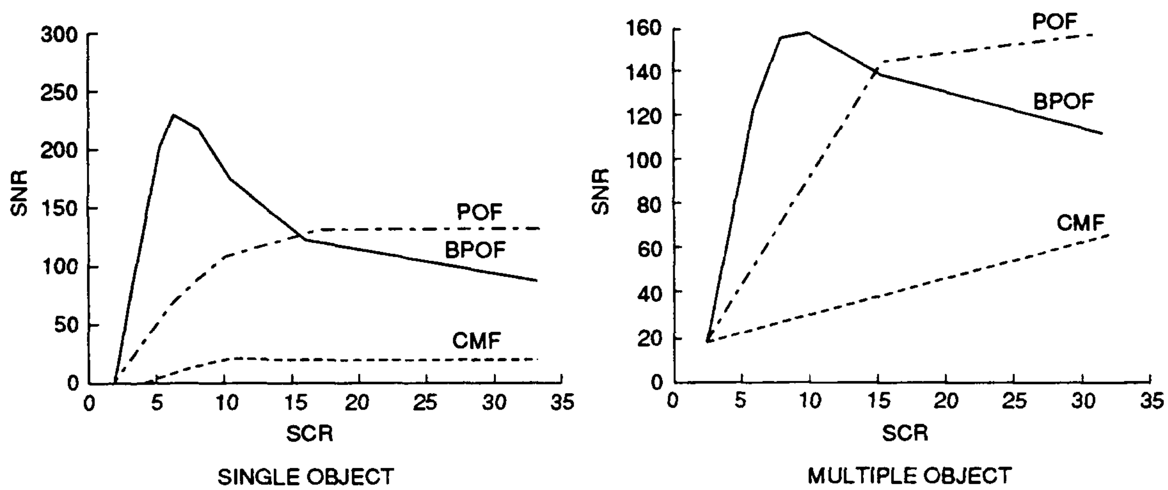

Figure 3. Signal-to-Noise vs Signal-to-Clutter for the Single and Multiple Object Scenes.

The POF and BPOF always perform better than the CMF, as we expected. However, a surprising result was the BPOF outperforming the POF for higher values of input clutter. In fact, the correlations shown in Figures 1 and 2 are made from the original untouched scenes where the SCR is 3.3 for Figure 1 and 3.1 for Figure 2. Although the peak value of the correlation is always greater for the POF, the BPOF correlations are less noisy yielding the results shown in Figure 3.

4.2 DC Block

The effect of varying sized blocks in the filter plane on the SNR vs SCR was studied. These blocks were a single pixel (DC component), a 3 x 3, and 5 x 5 block of pixels centered on the DC component frequency. The effect of the single pixel block on the single and multiple object correlations is shown in Figure 4.

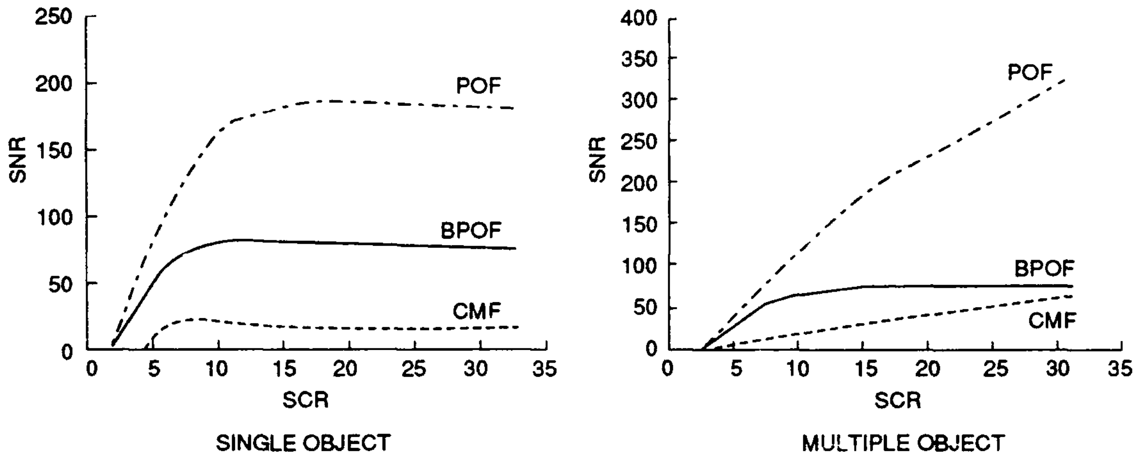

Figure 4. Signal-to-Noise vs Signal-to-Clutter for the Single and Multiple Objects with Single Pixel Block.

The effect of the single pixel block on the correlations of Figure 1 is shown in Figure 5. Note the presence of a peak in all three correlations.

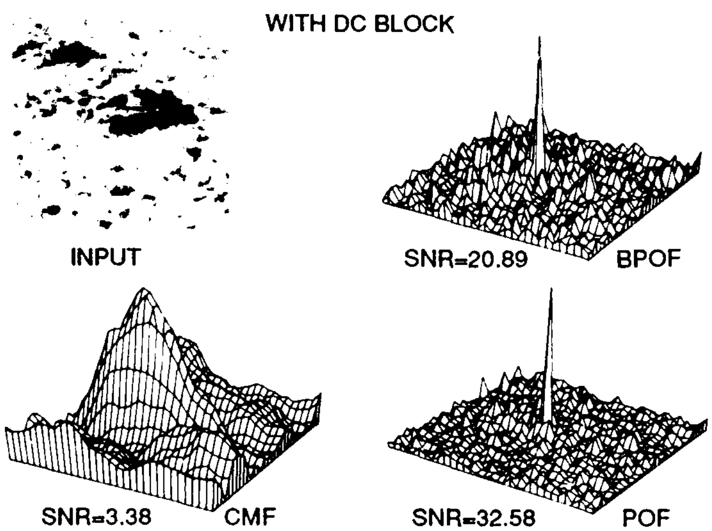

Figure 5. Effect of the Single Element Block on the Correlations of Figure 1.

This block has the general effect of increasing the SNR for the POF while lowering that of the BPOF. The POF now dominates the BPOF for all levels of SCR while the CMF remains virtually unchanged. A plot of the SNR vs Number of Blocked Pixels using the single object scene with a background multiplicative factor of 1.0 (original scene) is shown in Figure 6.

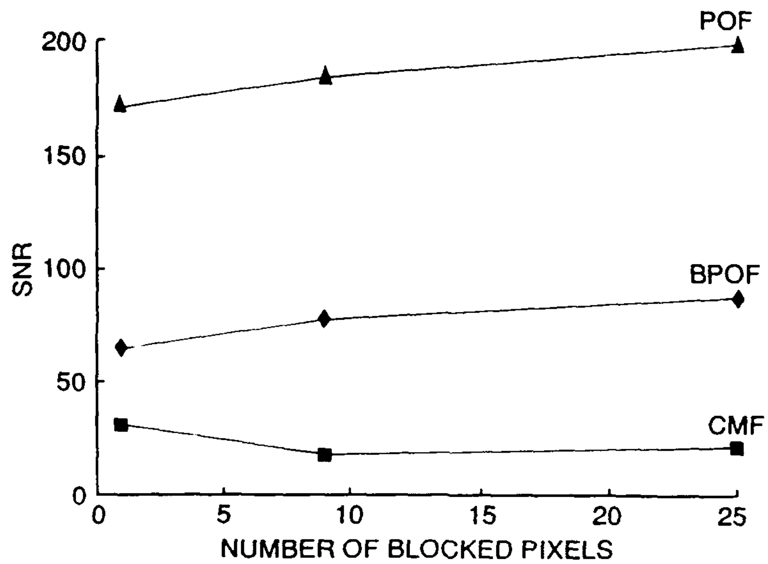

Figure 6. Signal-to-Noise vs Number of Blocked Pixels. The blocked are centered on the DC frequency.

The effect of the larger blocks is to slightly increase the SNR fo· .he POF and BPOF and reduce SNR for the CMF.

5. CONCLUSIONS

We have investigated the effects of varying background clutter of the performance of the CMF, POF, and BPOF. We propose a new metric for SCR that is based on the standard deviation of the clutter. We implement a similar criterion for determining the SNR in the correlation plane. These metrics are justified since the type of noise present in the input scene is not gaussian in nature and the constraints of wide-sense stationarity do not apply. We have found the POF and BPOF always outperform the CMF as expected, but the BPOF yields higher SNR for inputs with lower SCR (higher clutter). By introducing a block in the filter plane, we cause the POF to have higher SNR for all levels of SCR with the size of the block not being very important.

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