Ground exploitation using a binary phase-only optical correlator

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ABSTRACT

Experimental results of an optical binary phase-only correlator using aerial imagery for ground exploitation is presented. The correlator uses magnetooptic spatial light modulators (SLMs) for dynamic operation. Input images to the correlator originate from actual aerial imagery containing aircraft and a variety of distortions. Digital image processing techniques are used on images before being input into the optical correlator to enhance the performance of the system. Filters or templates used as a database for the system are derived from models of aircraft. Rotation and scale invariance is achieved through an adaptive filtering technique in which filters are displayed sequentially against an input image. Experimental results are presented which show that the system performs well with different types of segmented images.

1. INTRODUCTION

Autocorrelation experiments have shown that a phase-only filter (POF) in an optical correlator performs better than a matched filter [1]. Furthermore, it has been shown that the use of a POF produces a narrower correlation peak and exhibits improved discrimination in comparison to the matched filter. Binary phase-only filters (BPOFs) have been introduced which are POFs whose values of phase are limited to binary operation. BPOFs have been shown to give comparable performance to that of POFs [2]. They are of additional interest because they can be implemented with commercially available spatial light modulators.

A significant problem in optical pattern recognition is that a matched filter is sensitive to scale and rotation changes of an input pattern. An object viewed from a different angle or distance from which a filter was made may not correlate well with the filter, and the object may not be identified.

One solution is to make filters which correspond to all possible views of the object which is to be identified. By examining the correlation response of filters which are scaled and rotated versions of the reference object, a threshold value can be set which will determine the object's presence if the threshold is exceeded [3]. The different filters may be changed sequentially;

however, care must be taken because a large number of filters may exist which could slow the recognition process. Alternatively, the summing of filters have been proposed as a way to reduce the number of filters needed [4].

Using spatial light modulators, it is possible to dynamically display filters which correspond to different views of an object to achieve rotation and scale invariance in an optical correlator. Spatial light modulators have speeds which make this method a viable approach. A general adaptive matched filtering technique has been described which shows how natural invariances of input objects can be used to determine the minimum number of templates needed to achieve invariance coding [5]. For a given recognition criterion, the number of templates varies with the pattern structure.

In this work, a rotation and scale invariant BPOF optical correlator is described which uses the adaptive filtering technique to examine aerial views of airfields. The correlator uses magnetooptic spatial light modulators (SLMs) for dynamic operation. Both theoretical and experimental results are presented.

2. ADAPTIVE MINIMUM FILTER APPROACH

Displaying single templates sequentially to achieve a type of invariance can be effective if the templates are chosen on the basis on some optimality criteria [6]. The number of templates required to identify an object for a variety of scale and rotations will depend on the reference pattern.

To examine the correlation response of scaled and rotated versions of a reference, a generalized autocorrelation function has been defined as [5,6]

$$C(u, v; \alpha, \theta) = \iint_A h(\xi, \eta) , h(x + u, y + v) \; dx \, dy \, , \qquad (1)$$

where α and θ and are the scale change and rotation of the input pattern relative to the reference pattern respectively, and ξ and η are coordinates for the input pattern which has undergone a rotation and scale change according to

$$\begin{bmatrix} \xi \\ \eta \end{bmatrix} = \propto \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} . \tag{2}$$

The relationship of $C(u, v; \alpha, \theta)$ as a function of α or θ shows the dependence of the correlation response of the reference pattern on rotation or scale changes respectively. Of course, reference patterns can be chosen which have an inherent invariance. For example, a circle will show rotation invariance; however, most references of significant complexity do not exhibit such a strong inherent invariance.

Much work has been performed on developing methods to make the response of Eq. (1) relatively constant. Methods using circular harmonics have been developed which allow Eq. (1) to be constant relative to rotation [7,8]. Additional methods use a combination of reference patterns combined into one filter to achieve invariance [4,9]. For all methods, a common technique of identifying a match between an input and a reference is that the height of the correlation peak is above some predetermined threshold value. When the correlation peak exceeds the threshold value, the presence of the reference object is indicated. For BPOFs, Eq (1) will fall below the threshold value relatively quickly whenever α varies from 1 or θ varies from 0. Therefore, additional reference patterns or templates must be generated to achieve invariance.

The number of templates to achieve rotation and scale invariance is determined by a threshold value of a correlation peak and an invariance surface $I(\alpha, \theta)$ defined as [5]

$$I(\alpha, \theta) = \max \left\{ \iint_A h(\xi, \eta), h(x+u, y+v)\ dx\, dy \right\} . \tag{3}$$

Additional templates are generated when Eq. (3) falls below the threshold value. For example, all reference templates are cross-correlated with an input image and if the correlation response exceeds the threshold value, the presence of an object is indicated. The minimum number of templates will depend on both Eq. (3) and the threshold value. For a given $I(\alpha, \theta)$, the number of templates will increase as the threshold value increases. Using this approach, translation, scale, and rotation invariance can be achieved with an optical correlator.

3.0 SCALE AND ROTATION INVARIANCE

A set of templates to provide rotation invariance can be determined from the relationship of Eq. (1) with respect to θ. The technique is demonstrated by determining the minimum set of templates for a 128 x 128 reference image shown in Fig. 1. The reference image is derived from a model and is used to help design the correlator to identify the same type of aircraft as in the model from aerial imagery.

The POF for a reference template can be written as

$$H(u,v)=\exp(-i\phi(u,v)) \tag{4}$$

The values of the filter in Eq. (4) are set to either 0 or π at each pixel to create a binary phase-only filter (BPOF). If the calculated phase angle was between 0 and π, then the phase at that pixel was set to 0. If the calculated phase angle was between 0 and $-\pi$, then the phase at that pixel was set to π. Other methods have been employed to create a BPOF where the threshold phase angle may lie at different axes [10,11].

To find $I(\alpha, \theta)$, the transform of the input image is rotated by different values of θ, and each rotated input is correlated with the reference using an FFT algorithm. The maximum height of the correlation peak for each value of θ is a point on the $I(\alpha, \theta)$ curve. The resulting relationship is shown in Fig. 2. The data is normalized such that the height of the correlation peak at $\alpha=1$ and $\theta=0$ is the maximum value.

The minimum number of templates for a given $I(\alpha, \theta)$ is determined by a threshold value. For example, a threshold value can be arbitrarily chosen at 50% of the maximum value of $I(\alpha, \theta)$. From Fig. 2, a template would have be generated every four degrees. If a higher threshold is chosen, then the number of templates would increase.

It may be possible to store templates for only 0 to $\pi/2$. The templates in other quadrants are closely related to those in the first and may be easily generated by computer. Therefore, only one quadrant of templates can be stored to reduce the total number.

A set of templates to provide scale and rotation invariance for the image in Fig.1 is determined from Eq. (1). The scale and rotation dependence (Eq. (1)) of the image in Fig. 1 is shown in Fig. 3 for a BPOF. Using the same technique to gain rotation invariance, rotation and scale invariance may be achieved by using the proper templates.

Scaled versions of the reference template will affect rotation sensitivity. In an extreme example, if the size of the template is a few pixels, then an object may be rotated through a large angle until another template is needed.

4. EXPERIMENT

4.1 Optical system

The experimental set up consisted of an optical correlator with a Semetex spatial light modulator in both the input and filter planes with a computer controlling both devices. A camera was placed in the correlation plane to examine the output of the system. The SLM in the input plane was a 128 x 128 pixel device, and the SLM in the filter plane was a 48x48 device.

The use of a filter SLM with lower spatial resolution than the input SLM can have several advantages. An important practical consideration is that the cost of the filter SLM is about one-third the price of the input SLM for our magnetooptic devices. Another advantage is that the length of the system may often be made shorter, the amount depending on the specific SLMs being used. The focal length of the system is proportional to the resolution of the filter SLM if other factors remain constant. We used a configuration similar to that of a 2f correlator [12]. The length of the system measured from the input SLM to the correlation plane was 1.6m.

Another advantage of a reduced-resolution SLM in the filter plane is the potential for faster operation. Because less data would be transferred for an electrically addressed device, the possibility for more frames to be transferred given a constant data rate exists.

In computer simulations, the correlator with a 48 x 48 filter performed virtually the same as with a 128 x 128 filter. However, the reduced-resolution filter is slightly less sensitive to scale and rotation changes than the 128 x 128 filter.

4.2 Experimental results

Using the simulation data (Fig. 3) from the scale and rotation dependence of the BPOF for the image of Fig. 1, templates were created to achieve scale and rotation invariance. A reference template was made in increments of 4 degrees and scale factors in increments of .1. Using such templates the resulting correlation response should show a minimum correlation height which is about 50% that of the maximum value.

Using the optical correlator, the image in Fig. 1 was rotated through 10 degrees in 2 degree increments and through a scale factor of .7 to 1.0 in increments of .05. The filters were displayed sequentially and maximum correlation height for each input was recorded. The results show an invariance surface which was experimentally found and shown in Fig 4. It shows what the correlation heights look like for different values of scale and rotation of the reference image.

Since we are identifying a match of the input and reference by a threshold value of a correlation response, the peak height due to noise is also of interest. In addition to the correlation height, the signal-to-clutter ratio (S/C) was measured [13]. The S/C here is the ratio of the correlation peak to the next highest peak. The experimentally measured S/Cs are shown in Fig. 5. They show an average of about 6 db. They could be significantly higher but are limited by the light throughput of our system.

Actual aerial gray-level images were used as inputs to the correlator system. They consisted of a variety of visual and IR images containing different aircraft images of airfields with many distortions. Different input scenes were used as inputs to the correlator. A typical example is shown in Fig 6. The images were digitized then converted to binary for display on the input SLM of the optical correlator.

The correlation results strongly depend on the input and preprocessing. Images must be very similar to the reference after preprocessing to achieve a useful correlation response. On the other hand, the entire silhouette of an image did not have to be produced to achieve a correlation peak. A thresholding technique was used here to convert from a gray-level input to a binary image for display in the correlator. The result of thresholding of Fig. 6 is shown in Fig. 7. Typical good correlation heights were about 25% of that shown in Fig. 4. The S/C was usually slightly less that of Fig. 5.

5. CONCLUSION

Using an adaptive filtering technique, scale and rotation invariance can be obtained in a BPOF correlator. Excellent results can are obtained whenever the reference object appears in the input scene. When actual aerial imagery is used, the correlation height is significantly reduced when compared to the autocorrelation of the reference. Gray-level input images can be used with a binary spatial light modulator in a correlator system if the input images are preprocessed correctly. The inputs to the correlator must be very similar to the reference to obtain a good correlation response. In contrast, an image may not have to be well segmented from the background. Since the BPOF has excellent discrimination ability and emphasizes the edges of an object, it is sufficient to recognize an object when a substantial portion of the edges of an object are segmented with a reference which contains the silhouette of an object.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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Fig. 1 Reference image

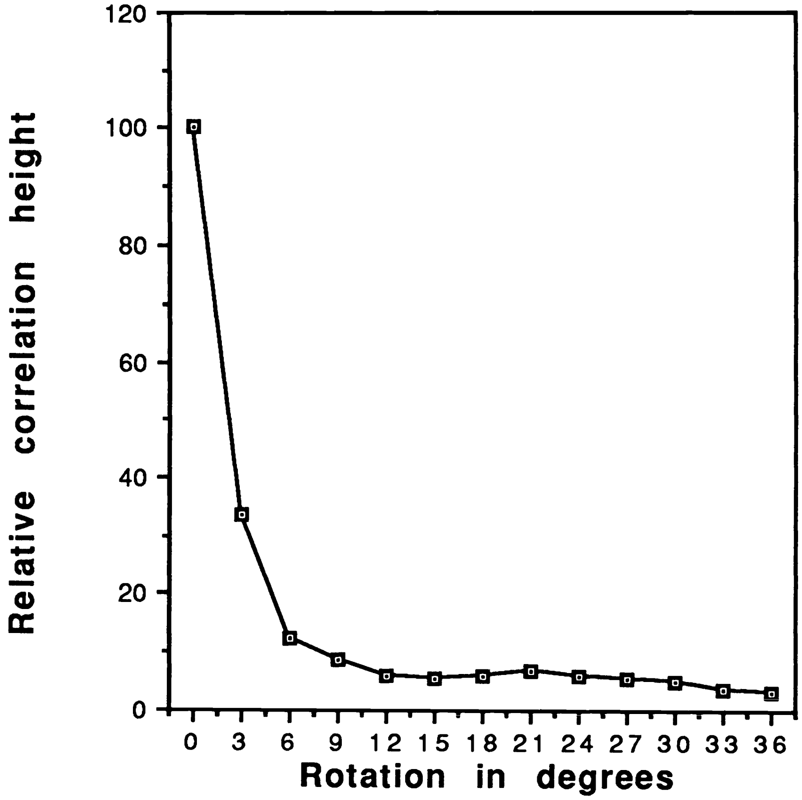

Fig.2 Eq. (3) vs. angle of rotation for Fig. 1 using a BPOF

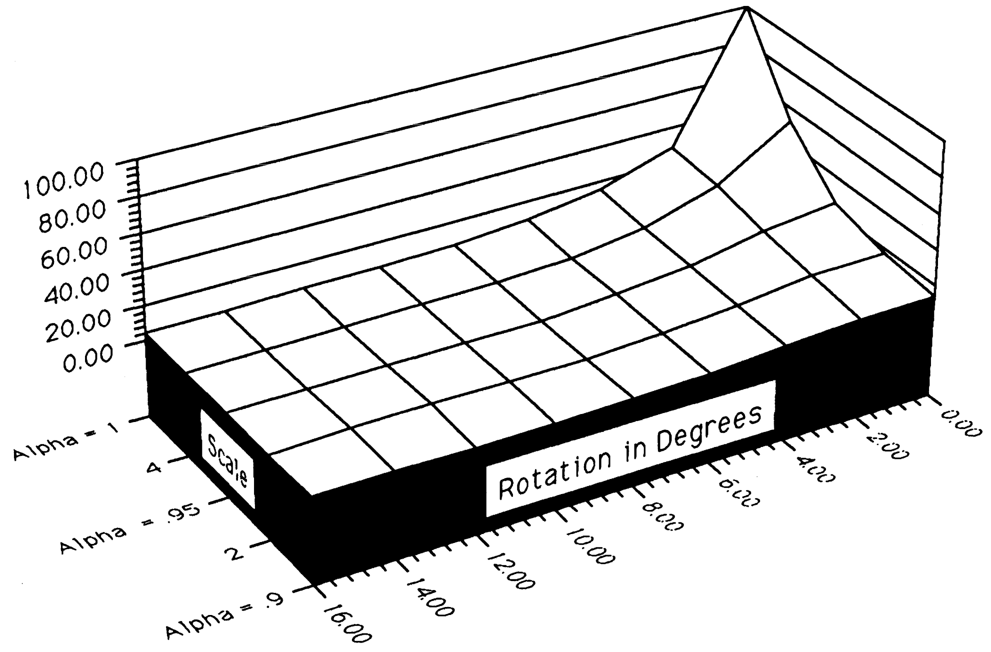

Fig.3 Eq. (3) scale and rotation response for Fig.1 using a BPOF

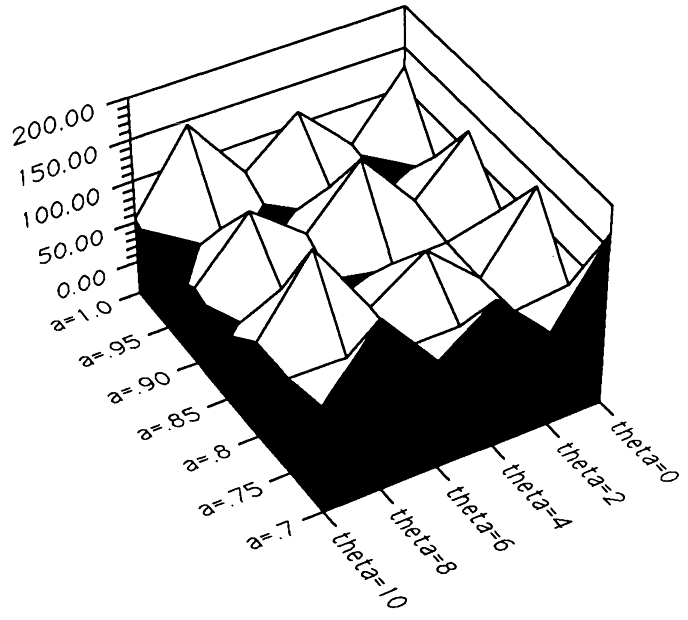

Fig.4 Experimental results for Eq. (3) for Fig.1using a BPOF

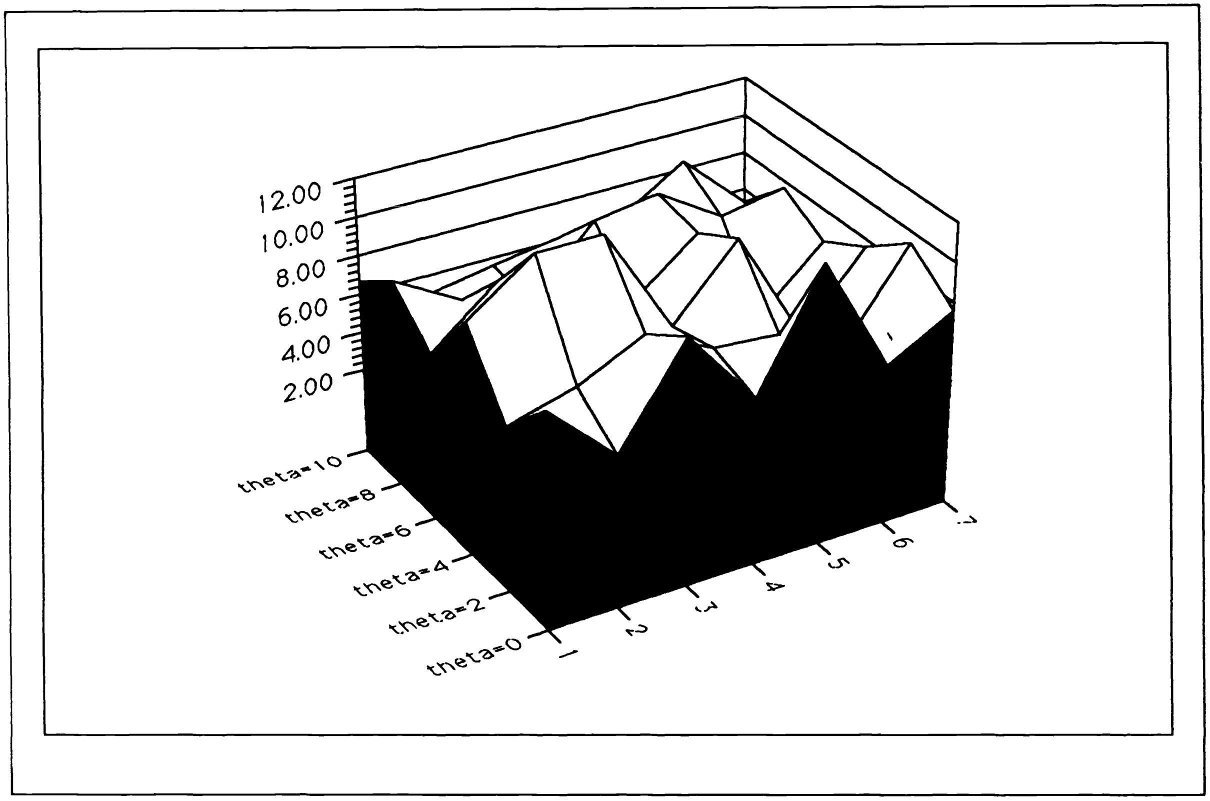

Fig. 5 Experimentally obtained S/C for a range of scale and rotation values

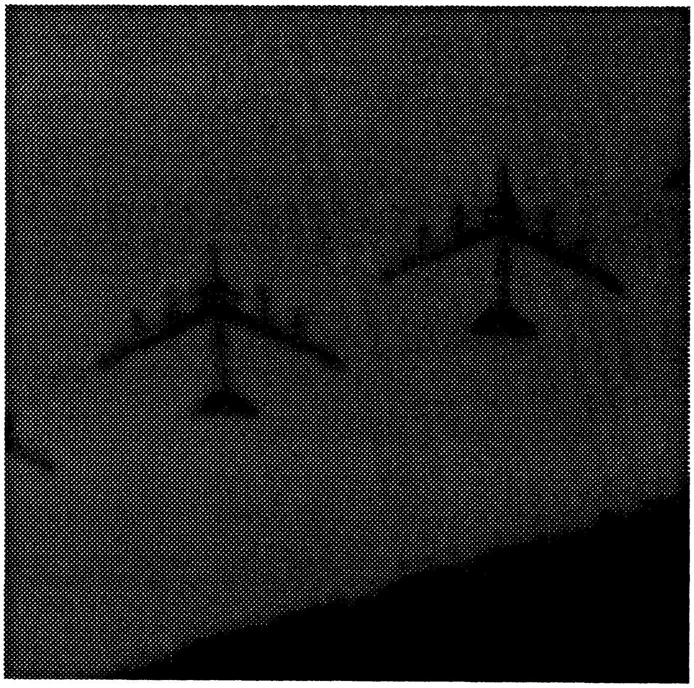

Fig. 6 Example of input imagery

Fig. 7 Example of imagery after preprocessing