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PHOTONIC SEEKER DEVELOPMENT.(U)
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PHOTONIC SEEKER DEVELOPMENT (U)

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INTRODUCTION

Ideally, a seeker system to be used for target identification and missile guidance should be able to recognize the target over an extended set of ranges, orientations and aspects. In the most simple scenario a single feature such as a characteristic infrared emission or designation of the target by an aimed laser spot will suffice. However, for autonomous seekers which have to seek out and destroy energy targets without the aid of laser designators or where the differentiation between friend or foe is more difficult, far more information has to be processed than may be possible by electronic means.

Consider the problem of identifying and correctly locating a single scale, orientation and aspect of an enemy vehicle in a snapshot taken with a typical instamatic camera. For this example we will take the focal length of the lens to be 2 cm, the lens aperture to be 1 cm, the wavelength of the light to be 5×10^{-5} cm and the field of view 1 cm x 1 cm. The numbers are useful only for order of magnitude calculation and need not represent an actual system. In the image plane the size of the resolution elements is 10^{-4} cm. Thus, the image may be thought of as a $10^4 \times 10^4$ array of resolvable elements. To recognize and locate the tank, the optimum estimator can be shown to be the cross correlation between a known image of the tank and the image to be searched. For an image consisting of $10^4 \times 10^4$ resolvable points, this involves computing two separate $10^4 \times 10^4$ point Fourier Transforms, multiplying the two together then forming the $10^4 \times 10^4$ point Fourier Transform of the resultant. A total of about 10^{10} multiplications is involved. The task of doing this at T.V. frame rates requires

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about 10^{12} multiplications per second and is well beyond the capability of any digital computer. Of course one could relax the requirements considerably in terms of number of resolution elements or processing rate, but only at the cost of reduced performance.

The photonic correlator, however, has such a capability today. It has the added advantages of low power consumption, mechanical simplicity and it can be made small enough to fit comfortably into a submissile. There are, however, several limitations which must be overcome before the use of photonic correlators become a reality for missile systems. These include the cost of the light modulator and the need for extending the memory of the photonic correlator to include an extended set of target scales, sizes and orientations. The problem of cost for the light modular appears to be one of manufacturing techniques and it should be possible to produce low cost devices cheaply enough in suitable quantities. The need to extend the memory of the correlator has been the subject of much of our recent research on the use of photonic correlators.

The MICOM Photonic Correlator - An Overview

The science of photonic optical information processing relies heavily on the Fourier Transforming Properties of Lenses (1). This was applied by A. B. Vander Lugt of the University of Michigan's Radar Laboratory, who, in 1963, demonstrated a new technique for synthesizing matched filters for coherent processors (2) (3).

Figure 1 represents the two stages of coherent image processing using Vander Lugt filtering techniques. In Figure 1A, a reference scene on a transparency of amplitude transmittance (x,y) is illuminated by a source of coherent light. The transparency is in the front focal plane of the Fourier Transforming lens L_1. In the back focal plane is located a photographic plate. Exposure of the plate to the transformed image (x,y) simultaneously with a reference beam produces what is called a matched spatial filter of the reference scene. Subsequent to development, the plate is re-inserted in the optical system as in Figure 1B. In this case the reference beam is removed and a new input transparency g(x,y) is inserted. The property of the matched filter is that in the arrangement shown in Figure 1B, the detected output in the cross correlation of f(x,y) and g(x,y), i.e., a bright spot will appear in the output plane if g(x,y) contains sufficient information about f(x,y). Furthermore, the position of the spot is a function of the position of the object located in g(x,y). Thus, the photonic correlator can effectively detect the presence of a test object in a given field of view.

As an example of the technique Figure 2 shows an image of a sedan used to make a Vander Lugt filter for the photonic correlator. Figure 3 shows the response of the correlator to a series of scenes showing the same vehicle driving along a highway. The lower set of photographs show the response of the photonic correlator to the input scenes. A bright correlation spot appears in the output. The existence of this spot identifies the existence of the automobile in the input scene and the position of the spot denotes the position of the automobile. In a dynamic situation the photonic correlator follows the target at T.V. frame rates.

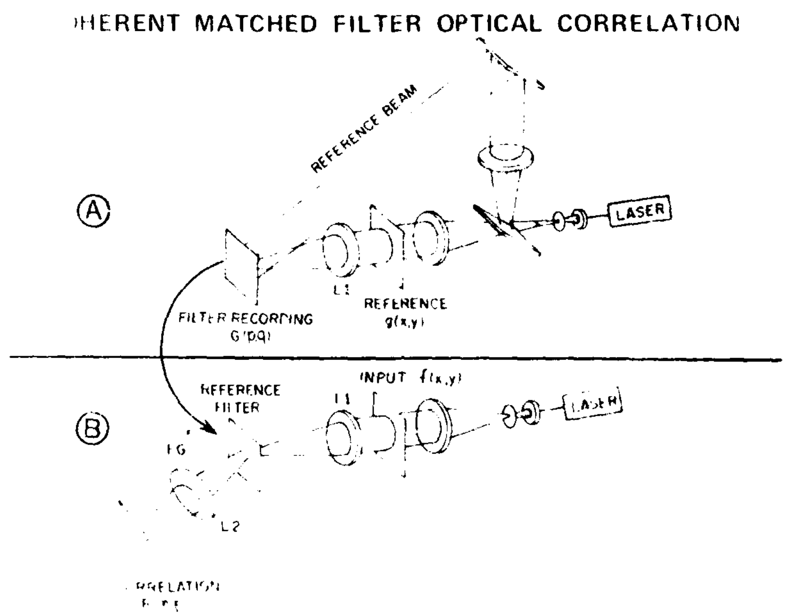

Figure 1. Typical Optical Correlator (A) Method of Recording Filters, (B) Method of Obtaining Correlations.

Real-time applications of the photonic correlator were demonstrated by Guenther et. al (4) of MICOM by utilizing a liquid crystal light modulator to generate the spatially coherent input scene. This enabled the correlator to recognize and track targets at about T.V. frame rates. In 1980, Duthie et. al (5) also of MICOM reported a further improvement in the photonic correlator, namely, the use of solid state laser diodes rather than bulky, fragile gas lasers. The combination of the use of real-time input devices and solid state light sources spurred interest in developing a compact correlator as a practical tracking seeker. Figure 4 shows a possible configuration of such a system.

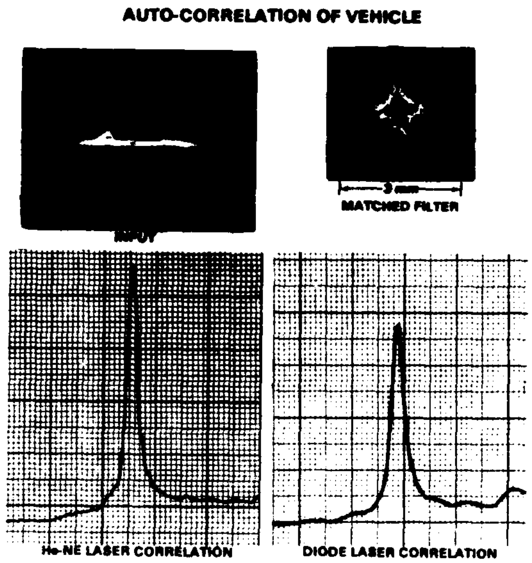

Figure 2. Example of Correlator Input (a) Input Object (b) Matched Filter of some Object.

Increased Memory for the Photonic Correlator

Major improvements need to be made in the capacity of a photonic correlator to store and address a large number of reference images before the photonic correlator can be regarded as a serious contender for missile guidance and tactical homing applications. Leib et. al (6) have designed an optical matched filter correlation system in which a large array of holograms can be stored in a matched filter through the use of a multiple number of holographic lenses. Theoretical predictions of a capability to store up to 2500 matched filters have yet to be realized in the laboratory.

A new method of addressing an array of matched filters has been developed by Liu and Duthie (7) at MICOM. In the basic correlator system of Figure 1, a phase screen is placed in the input plane. This screen has high optical transparency but spatially modulates the phase of the light waves. The periodic modulation is chosen so as to generate an array of islands in the Fourier Transform plane of the correlator. Figure 5 shows a photomicrograph of the phase screen while Figure 6 shows the array of islands found in the transform plane. Thus, the effect of the phase screen is to modify the light distribution in the back focal plane of the transform lens so that instead of a single spot, an array of spots is produced by a collimated input beam. In the present case, it has been found that a 5 x 5 array of spots can be engineered to carry the bulk of the light intensity.

VEHICLE TRACKING WITH
LASER DIODE CORRELATOR

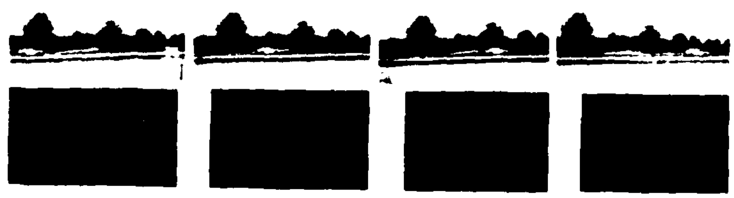

Figure 3. Tracking of Automobile using Optical Correlator

Furthermore, Liu and Duthie have demonstrated that at each spot, a matched filter, of the Vander Lugt type, can be located. These workers have demonstrated the effectiveness of each of the 25 spots individually at target identification and tracking.

Table 1 shows the measured intensities of the spots in the 5 x 5 array. The central (0,0) spot is certainly the brightest. The remainder, although not strictly equal are indeed equal to within an order of magnitude. Autocorrelations have been measured for matching input scenes with recorded filters of the same scene for each of the spots addressed individually. Previous work at MICOM has indicated that up to eight matched filters can be recorded at every spot or island in the Transform Plane. Thus, the potential exists for the storage of up to 200 matched filters in this system.

order	-2	-1	0	+1	+2
+2	.35	.35	1.17	.32	.23
+1	.43	.46	1.43	.42	.39
0	.96	.98	2.92	1.01	.91
-1	.48	.40	1.39	.41	.37
-2	.28	.29	1.00	.28	.27

Table 1. The Measured Relative Intensity Values in μW.

To date we have not made a complete filter array and addressed each in parallel. This requires precise alignment in the filter manufacturing stage and has to be done under computer control. Such an effort is currently underway at MICOM and should be completed shortly.

COMPACT VISIBLE-INPUT OPTICAL CORRELATOR

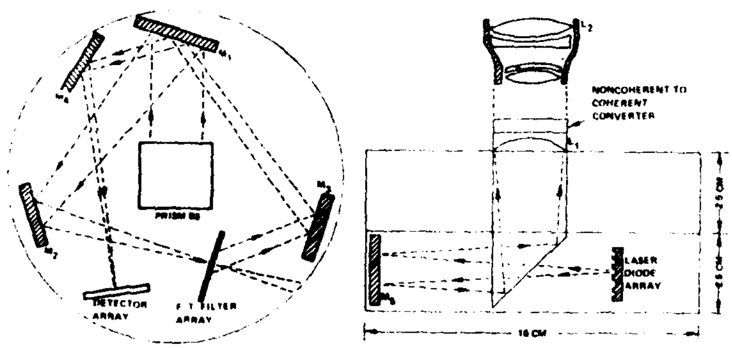

Figure 4. Proposed Design for Compact Optical Correlator.

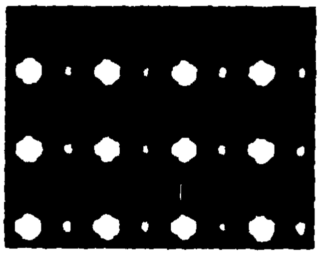

Figure 5. Photomicrograph of Phase Screen used to Multiplex the Number of Filters Addressed in Parallel. Period = 1/133 inches.

Non-Coherent Illumination

Whereas the optical correlator relies on the Fourier Transforming Properties of Lenses and requires good spatial coherence of the illuminating beam, no requirements are needed for temporal coherence of the light source. Indeed, several advantages may accrue if the laser or laser diode in the photonic correlator could be replaced by a thermal light source. First would be the advantage of cost, followed by advantage in terms of the absence of coherent or artiface noise. This noise is a direct consequence of the temporal and spatial coherence of the source and can be eliminated by using a broad band light source.

There is, however, a major problem in using a thermal source. The Fourier Transforming Properties of Lenses is a function of the wavelength of the light used. Thus, if a broad spectral source is used to read out a matched filter, then it will only be able to form a correlation over a very narrow band of wavelengths close to the wavelength used in making the filter. For example, Figure 7 shows the Fourier Transform of a

2-Dimensional Ronchi Grating when viewed in a coherent image processing system when illuminated by white light.

Instead of a set of discrete spots on a rectangular array, the lens generates a set of rainbow colored lines showing extreme chromaticity in the Fourier Transforming function

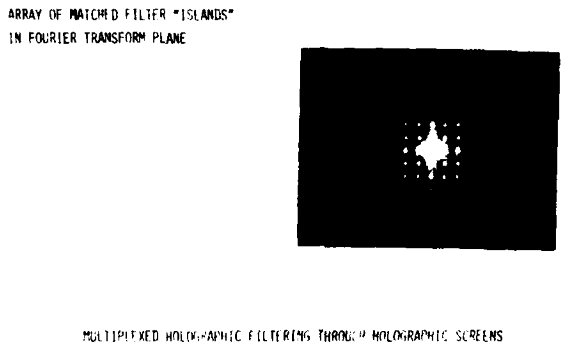

Figure 6. Array of Spots or Islands in the Transform Plane Produced by the Phase Screen. At each Spot in the Central 5 x 5 Region up to Eight Matched Filters can be Stored and Addressed in Parallel.

A solution to this problem has been developed at the University of Rochester (8) and has been improved on by Duthie and Upatnieks at MICOM. The optical arrangement is shown in Figure 8. The transforming process of a simple lens has been replaced by a train of two off axis holographic lenses, a simple refractive lens and a diffraction grating. The first lens is a combination of a thin lens of focal length F_o and an off axis holographic lens of focal length $- F_o$ at a wavelength λ_o. At other wavelengths it has a focal length $- F_o \lambda_o/\lambda$. At λ_o the effect of this lens is to diffract an input collimated into a collimated beam at an angle to the optical axis. At larger and shorter wavelengths the diffracted beams diverge or

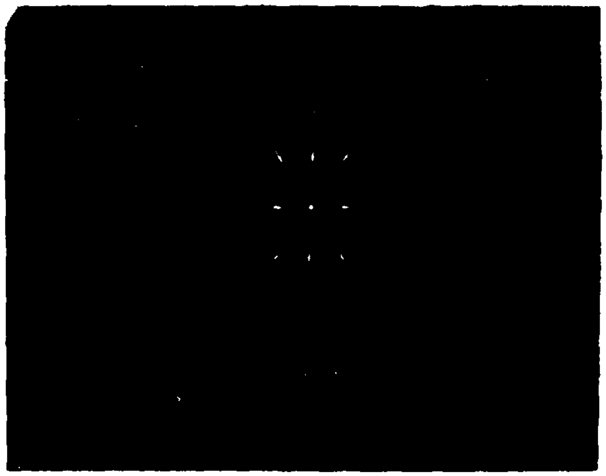

Figure 7. Conventional White Light Fourier Transform of a 2-Dimensional Ronchi Grating. Note the Extended Nature of the Individual Orders due to Severe Chromatic Effects.

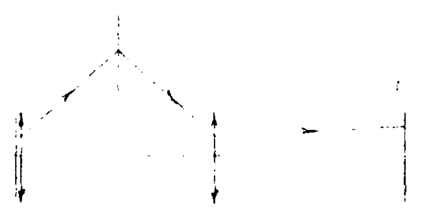

Figure 8. Optical Arrangement for Achromatic Fourier Transform System.

converge according to wavelength. The grating serves to deflect the beams back onto the converging holographic lens L_2 which has a focal length $+ F_0 \lambda_0/\lambda$. The net effect of these diffractions and propagations of the waves is to generate on the focal plane a Fourier Transform which is, to a high approximation, independent of wavelength. Figure 9 shows the Fourier Transform in white light obtained of the same 2-Dimensional Ronchi Grating as used for Figure 7. The chromaticity in the Fourier Transform plane has been effectively removed.

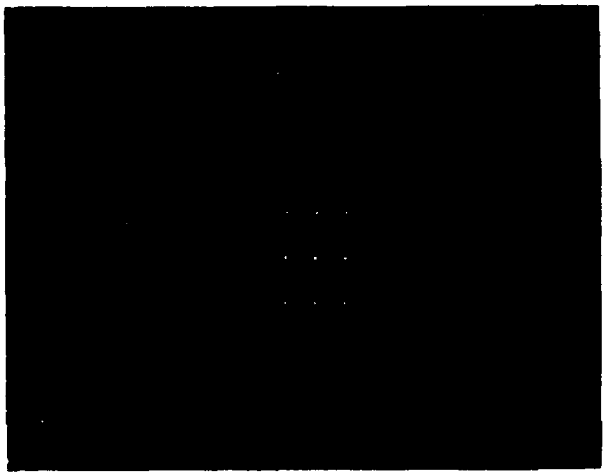

Figure 9. White Light Fourier Transform of 2-Dimensional Ronchi Grating using Optical Arrangement of Figure 8.

This type of optical arrangement has been effectively used to generate auto correlations between input and identical reference scenes. An additional element needs to be added to the system to make the final correlation achromatic - in this case a simple diffraction grating was used.

Results so far have shown a dramatic improvement in the apparent signal to noise of correlations obtained using white light rather than laser light in the achromatic correlator. Apart from the data and noise in the input scene, none of the other noise in the system was transformed achromatically and thus did not correlate over the entire spectrum of the source used - in this case a high intensity Hg vapor lamp.

Conclusions

Experiments have been performed which indicate a means to extend significantly the number of matched filters which can be simultaneously addressed in the photonic correlator. Results indicate that a total of 200 independent images of the target can be interrogated in parallel.

10 to the 13th power

This corresponds to an effective computation of over 10^{13} complex multiplications per second. The suggested method is mechanically simple, optically easy to implement, requires little power and can be fabricated into a compact unit.

Improvement in the signal to noise of a photonic correlator can be achieved by using an achromatic transform system and a thermal light source. At this time, however, the throughput of such a system is not sufficient to make a practical device. Whereas, efforts should continue to develop techniques to correlate using thermal light sources, the principal thrust for making a field operational system should, at this time, be concentrated on the use of laser diode sources together with the use of phase screens to extend the memory of these systems.

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