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OPTICAL CORRELATION SEEKER,(U)
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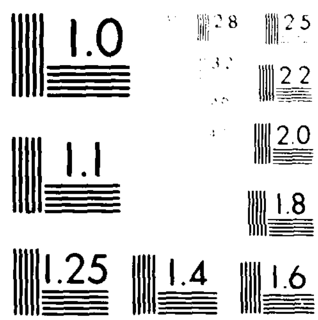
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OPTICAL CORRELATION SEEKER (U)

JUN 1980

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INTRODUCTION

A "super-smart weapon" which outperforms our smart weapons just going into the field, yet is much cheaper than those current systems? It sounds like the answer to the Army's prayer for a method to cope with a dramatically increasing threat. We think we have demonstrated the key ingredients of such a system, through the marriage of a long-term fundamental effort at the Missile Command, significant industrial developments, and recognition of how this developing technology can pay off for the Army.

Through the application of some recent existing developments in optical data processing, we can now propose to build a seeker which recognizes a tank by its image, homes on it, and destroys it. The seeker autonomously detects and locks on the target, provides guidance signals, reacquires if the target is lost, and retargets if necessary. The sensor will fit in a submissile, weigh under a pound, consume less than a watt of power, and possibly even cost under $100!

In this paper we will discuss the concept and its applications to set the stage for our interest. The bulk of the paper following will dwell on the technological advances we have made which make this concept feasible.

CONCEPT

The sections below will show how we have built an optical computer which can:

- o Autonomously acquire a target.
- o Provide guidance signals.
- o Discriminate.
- o Operate against a variety of predetermined targets.
- o Reacquire a temporary obscured target.

We will also show a significant development which will allow us to do this in a small inexpensive package.

Figure 1 demonstrates the operation of our laboratory computer. The image of the tank model is the desired target. The optical computer located this target in the input scene, and showed its location in the correlator output plane.

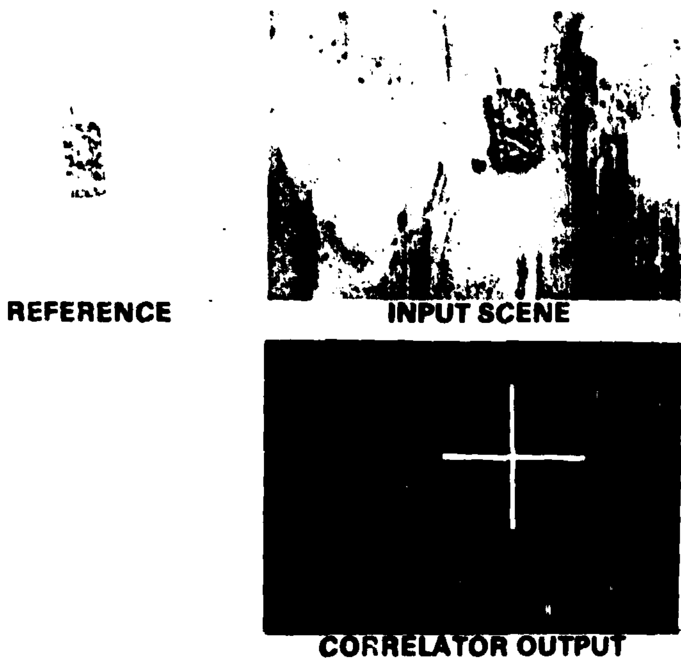

Figure 1. Demonstration of Optical Correlation

The optical computer could be used with any imaging sensor, such as radar, mm, or IR. But it has its greatest potential in a direct visible role, and we believe there are important applications in this role.

The conceptual seeker takes the form of Figure 2.

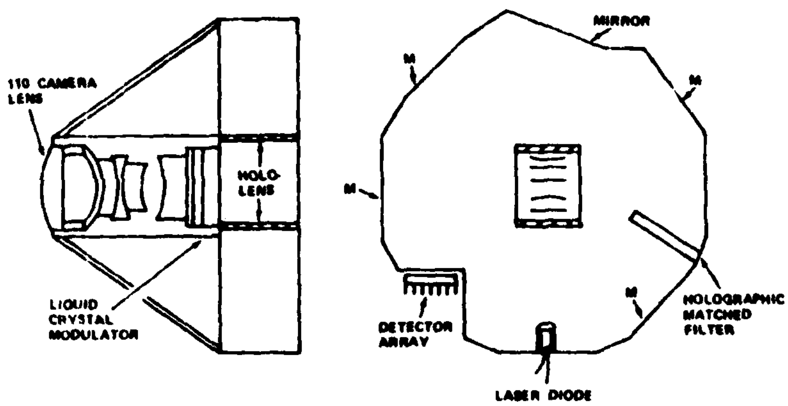

Figure 2. The Optical Correlator Seeker in a Visible Mode

This sensor is designed to correlate to a target from the top, as in Figure 3. It will recognize the target at any orientation, and operate over a wide span of distances to the target. It can recognize and discriminate between targets to about the same degree as a human can.

Unlike many other "top attack" sensors, the optical correlator does not need to search the field of view, or search the scene against the reference. This allows it the time to select targets of lesser value, or to pull a fly-out maneuver to look for targets, as in Figure 4.

The system could also perform some damage assessment, and retarget if possible, as in Figure 5. The high resolution allows us to detect smoke, flames, or debris flying off.

One application of our concept would be a guided mortar, such as GAMP. The guided mortar provides the infantry company with tank killing firepower. The target probably will be acquired with the human eye, so the visible operation of the optical seeker should be acceptable. The optical computer can be configured to fit within an 81 mm package, and if cheap enough, could be widely distributed.

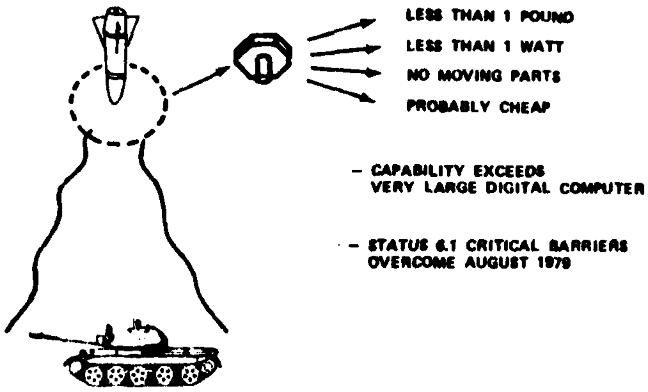

Figure 3. The Simplest Optical Correlator Seeker Works on a Top View

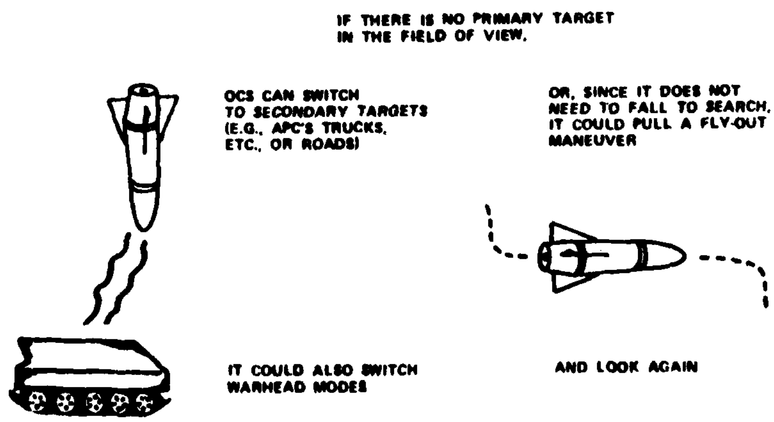

Figure 4. Alternate Targeting Mode

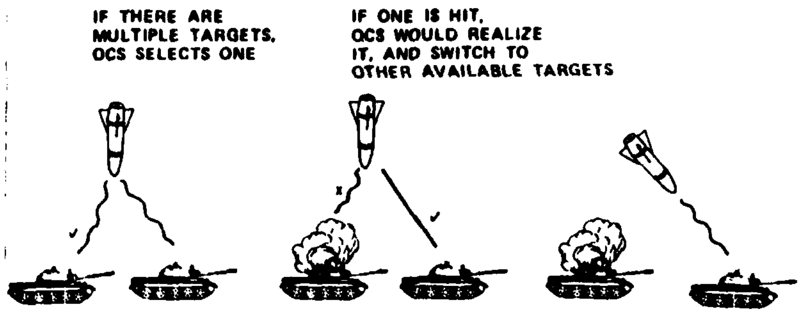

Figure 5. Damage Assessment/Detargeting

A top attack anti-tank missile is another role. Concepts (FFAST, Tank Breaker) using top attack are now popular, because of the vulnerability of the tank on top. In this concept a shoulder fired missile would pull a preprogrammed maneuver to fly a lofted trajectory, and then home on the top of the target.

The ASSAULT BREAKER concept, or Corps Support Weapon System, proposes to disperse submunitions over an area rich in targets. Coupled with long range target acquisition, this system would interdict fighting material on its way to the front.

In this role the exceptional computing power of the optical computer comes into its forte. This system automatically acquires and locks onto target. It can discriminate between targets of interest. I can search a stored reference target array, and select targets of highest value. It could go after tanks, trucks, buildings, roads, bridges, or whatever is deemed of value.

We optimistically expect that a given missile platform could carry more submunitions using this technology, yet at a greatly reduced cost. The higher versatility effectiveness of the optical system means it would be so effective that it would be worth having, even if it didn't work in fog. Inclusion of a few flares in the payload would provide for night-time operation. In Europe, morning fog can be quite prevalent, and last long enough for tactical use; but an interdiction role may allow early use of the weapon system or waiting a few hours for the right conditions.

COHERENT OPTICAL CORRELATION

Cross-correlation is a very effective method for recognizing images. The advantages of using optical processing for cross-correlation are due to the large information handling capacity of optical systems. A modest system can process scenes having over 10^7 resolution elements. Such a system handles two-dimensional data isotropically and in parallel with the processing time determined by the time required for data input and output. The large capacity of optical storage media can be used to provide rapid access to a large number of reference images.

The cross-correlation function is defined as

$$R_{fg}(\eta,\xi) = \int_{0}^{\infty}\int_{0}^{\infty} f(x,y)g(x-\eta,\ y-\xi)dx\ dy\ . \qquad (1)$$

In this equation, $f(x,y)$ describes a signal image (the real-time scene), and $g(x,y)$ describes a reference (the desired target). $R_{fg}(\eta,\xi)$ then describes how well the two match, and the location of a target in the scene.

This cross-correlation can be calculated through the use of Fourier transforms,

$$R_{fg}(\eta,\xi) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} F(p,q)G^*(p,q)\ \exp\left[-i(p\eta + q\xi)\right]\ dp\ dp \qquad (2)$$

where the Fourier transform of $f(x,y)$ is defined as

$$F(p,q) = \mathfrak{F}\left[f(x,y)\right] = \iint f(x,y)\ \exp\left[-i(px + qy)\right]\ dx\ dy\ , \qquad (3)$$

and G^* is the complex conjugate of the Fourier transform of $g(x,y)$.

To implement (2) using optical techniques, an optical system such as the one shown in Figure 6 is used. The reference scene $g(x,y)$ is placed in the front focal plane of the lens L1 and illuminated by coherent light; the Fourier transform $G(p,q)$ appears in the back focal plane. As can be seen in Figure 6, a reference beam is used to holographically record G , i.e., the amplitude and phase of G are recorded. The input can now be changed to $f(x,y)$

as shown in Figure 6(b). The hologram in the back focal plane of L1 diffracts the product of Fourier transforms FG* along the optical axis of L2. The lens L2 forms the inverse Fourier transform, i.e., $R(\eta,\xi)$ in its back focal plane.

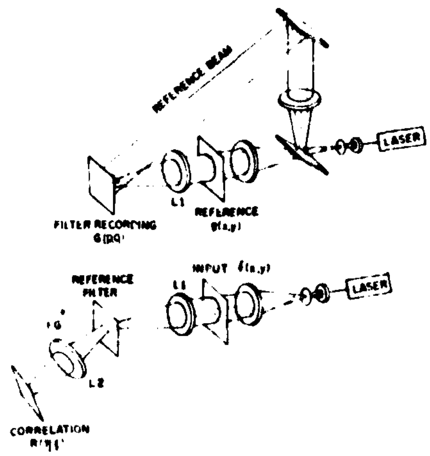

Figure 6. The Optical Correlator

This process was demonstrated above in Figure 1. The image of a tank model was used to form the reference filter as illustrated in Figure 1(a). This reference filter was matched against the input scene containing the tank as shown in Figure 1(b). The correlator input, a spot of light in a dark background, is shown in Figure 1 at the same scale as the input scene. The presence of the correlation spot identifies that the tank in the input scene is the same as the reference and the location of the spot designates the location of the tank in the scene. The small size of the correlation spot indicates the precision with which the tank can be located. A measure of this precision, the half-width at half-height of a trace through the correlation, was 1/12 of the tank width in this example; and the signal/noise limited accuracy was 1/50 of the tank width.

The laboratory correlator used in these experiments has been described previously (1). A major breakthrough a few years ago was the development of real-time data input through use of a liquid crystal light valve (2,3). MICOM participated in the funding of this development. The light source is a He-Ne laser operating at 633 nm or a GaAlAs diode injection laser operating at 820 nm. Reference filters are recorded on photographic plates with a He-Ne laser. When correlating with a diode laser source, a scale change of the input image is required to compensate for the change in wavelength from that used in filter recording.

Composite Filter

Earlier attempts at correlation guidance were sensitive to angular orientation. Filter multiplexing was tried as a way to solve this problem (4-5). Several reference filters, each of a different perspective of the vehicle, were recorded at the same spatial location in the Fourier transform plane. The exposure time of each of the N multiplexed filters was T/N, where T is the exposure time for a single reference filter. Since only vehicle recognition and location is required, the correlation functions of the superimposed filters coincide in the output plane.

Figure 7 shows a polar plot of the relative correlation peak amplitude for an eight-fold multiplexed filter. Images of the vehicle are displayed around the polar plot in Figure 7 to aid in visualization. Arrows on the graph indicate the orientation used in recording the eight superimposed filters. The single reference filter produced a correlation peak whose amplitude remained above 40% of its maximum over a 50° angular change. The eight-fold multiplexed filter demonstrated similar performance over 360°. This technique has solved the angular orientation problem.

A four-fold multiplexed filter demonstrated similar performance but the correlation peak dipped below 40% of the maximum value at two orientations. The choice of different recording positions and adjustment of individual filter exposure levels could make the angular response curve much more uniform.

A similar experiment successfully compensated for angle-of-view change in elevation. The technique of multiplexing is expected to work equally well for change of scale to operate over a variety of ranges to the target.

Discrimination

Does multiplexing destroy the filter's capacity to discriminate between various objects? A simple test was performed to compare the ability of the filter to discriminate against a different model. The results of this test are shown in Figure 8, where a single TV line through the correlation peak is displayed for the case when the input image was Model A and when the image was Model B. Model B was used to construct the filters.

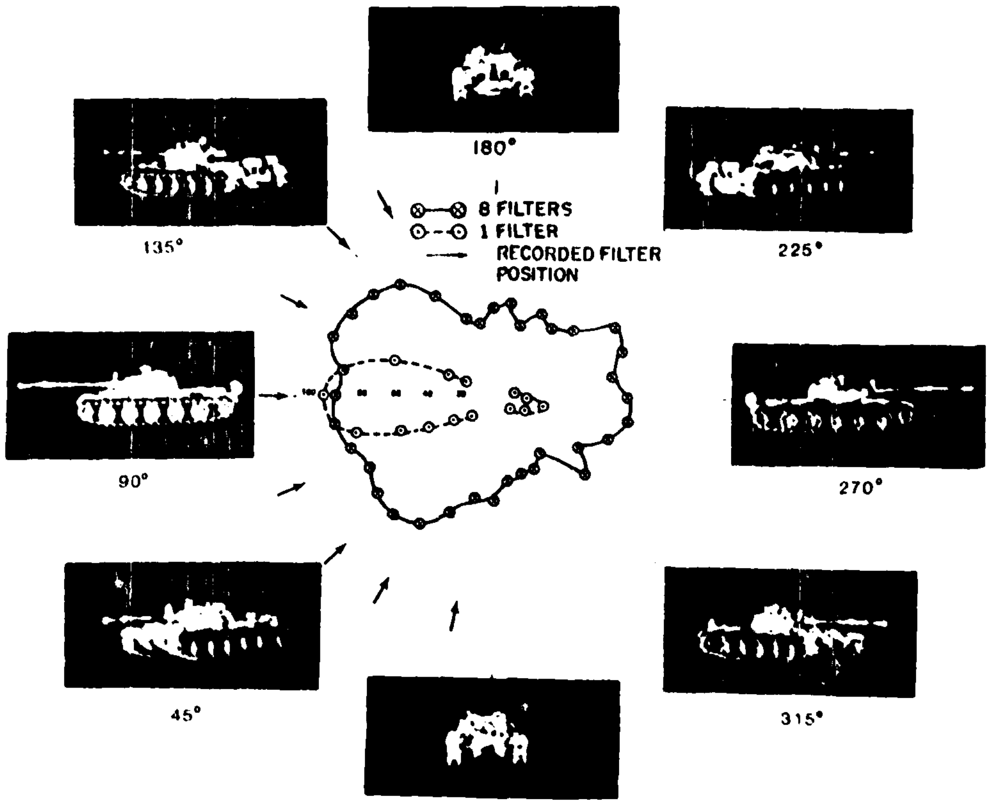

Figure 7. Correlation at any Aspect Angle with Multiplex Filter

The maximum peak amplitude for the eight-fold multiplex filter was unexpectedly high: one-fourth the amplitude obtained when using a single filter. Linear recording theory predicts that the correlation peak should drop to $1/N^2$ of that of a single filter for single filter contributions, or to $1/N$ of that of a single filter for simultaneous filter contributions (N is the number of superimposed filters). The abnormally large correlation peak amplitude may be the result of nonlinear recording and in-phase amplitude addition of the correlation peaks from individual filters.

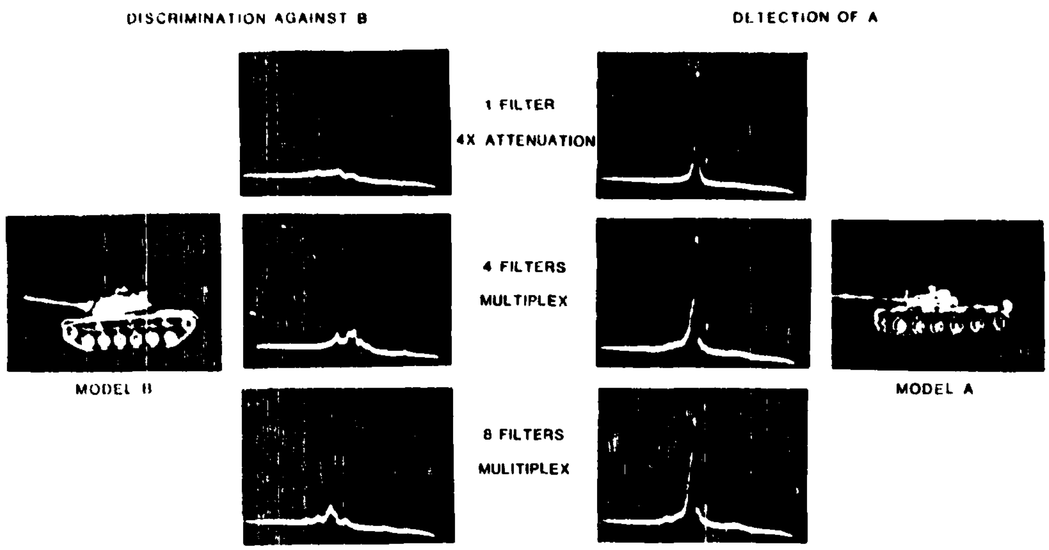

Figure 8. Target Discrimination with the Optical Correlator

Our explanation of the origin of the angular insensitivity of the multiplexed filter is purely speculative. The theory of two-dimensional moment invariants (6) may provide an explanation and might be used for the digital generation of this type of filter.

Multichannel Correlator

An input image can be correlated against a number of reference filters within one optical system (7). This can be used to obtain a correlation over a wide range of image angle or size, or it can be used to search for a number of different objects within the input scene. A filter array can be addressed by a holographic lens (8,9) or by multiple light sources (10). The use of a light source array to address a corresponding reference filter array is illustrated in Figure 9.

This allows each filter to be sequentially addressed, requiring no more light power or detector sensitivity than a single channel correlator. A search through a hierarchy of targets, e.g., tanks, armored personnel carriers, trucks, etc., can also be performed. A two-channel correlator has demonstrated continuous vehicle tracking (4).

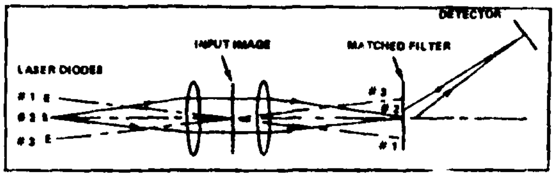

Figure 9. Multichannel Optical Correlator

Diode Laser Sources

One of the major barriers to fielded application of optical computers is the use of large, non-rugged gas lasers for the light source. We have solved this problem by designing and demonstrating a correlator which works with room temperature cw diode injection lasers. These lasers typically have an output power of 10 mW at 820 nm wavelength and require approximately 200 ma at 2.5V or 0.5W of input power. The microscopic size and low power consumption of these lasers make them suitable as light sources in a multichannel correlator. A correlator with up to a 5 X 5 element source array addressing a corresponding reference filter array is feasible (10). Suitable diode laser arrays are available from manufacturers. The IR wavelength and limited coherence of currently available diode lasers make them direct-holographic-recording impossible. However, we have developed an indirect technique for making filters for use in a diode laser correlator.

The light source temporal and spatial coherence requirements for coherent optical correlation have been analyzed previously (11,4). Relatively low source coherence is required for low resolution input imagery.

The maximum spectral width, $\Delta\lambda_m$, that will have a negligible effect on the correlation is

$$\Delta\lambda_m = \frac{\lambda_o}{N} \quad , \qquad (4)$$

where λ_o is the light source wavelength and N is the number of resolvable points across the image input to the correlator. For correlation on an entire TV screen input using a diode laser with λ_o = 820 nm, the maximum spectral bandwidth is 820 nm/512 or 1.6 nm. In practice the temporal coherence requirements are much less than this due to lower input image resolution and due to the lower spatial frequency distribution recorded on the filter.

A change, S , in input scale is equivalent to a wavelength change

$$S = \frac{\Delta\lambda}{\lambda} \quad (5)$$

therefore, the measured scale change tolerances can be used to determine the spectral width tolerances for the correlator light source. Our earlier work indicated a ± 8% scale change tolerance for vehicle recognition (4,8), so the light source bandwidth can be 0.16 λ_o or 130 nm. Diode laser spectral bandwidths are 2 nm or less.

The spatial choerence or source size requirements can be determined by measuring the tolerance of the correlation to lateral filter displacement. A filter displacement is equivalent to a source displacement scaled by the ratio of the transform lens and collimating lens focal lengths. In previous experiments (4) using a coherent helium-neon laser source, a ± 12 μm filter displacement resulted in no more than a 3 dB decrease in correlation amplitude, indicating that a 24 μm diameter source would be acceptable. An advantage of using a less spatially coherent source is that the matched filter alignment requirements are reduced (11,12). Matched filter correlation using a large spatically noncoherent source has been demonstrated (13).

These considerations indicate that even light emitting diodes, with 30 nm spectral width and 200 μm diameter emitting area, have adequate temporal and spatial coherence for optical matched filter correlation. Light emitting diodes will be evaluated in future work.

A comparison between coherent optical matched filter correlation using a helium-neon laser and a diode laser is shown in Figure 10. The photograph of the automobile was used to make a reference filter. This picture was autocorrelated using a helium-neon and diode laser source with approximately 10 mW output power. Traces through the correlation spots obtained with the two sources are shown. The correlation linewidths are the same, as is expected from the preceding discussion of coherence requirements. This filter was able to track the vehicle as it moved across the scene, to better than 1/20th the vehicle size.

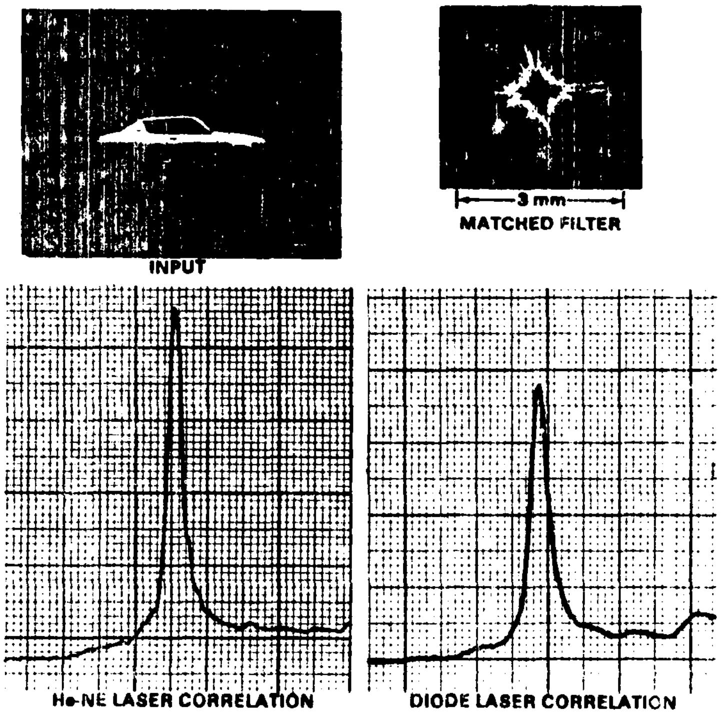

Figure 10. Performance of the Diode Laser Correlator

Packaging of a correlator in a configuration that can be fitted in a small missile was also considered. Two miniature correlators were designed, one a cylindrical package with the image input at the center and the other rectangular with the input at one end.

Figure 2 showed a correlator folded into a 100 mm diameter cylindrical package. The input device is an optically addressed liquid crystal light valve. The correlator output is detected by a solid state CCD detector array.

Figure 11 shows a correlator design contained within a transparent solid. This monolithic construction increases mechanical rigidity and ruggedness and eliminates the possibility of optical surface contamination. If an electronic input coherent light modulator (14) is used, imaging lens L_2 would be eliminated. This correlator is compact enough to fit within an 81 mm mortar projectile.

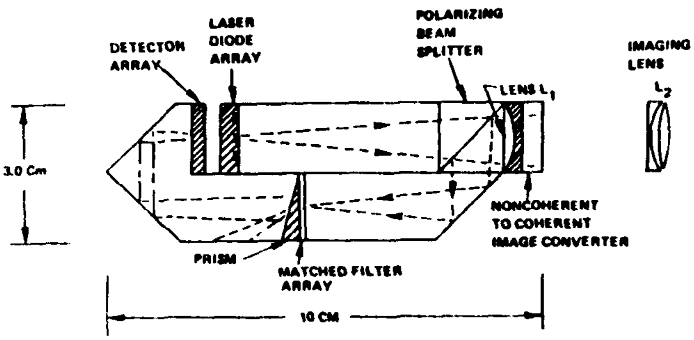

Figure 11. A Monolithic Optical Correlator

CONCLUSIONS

The developments in the field of optical data processing over the past few years make this a technology ripe for exploitation by the Army. The work described in this paper has demonstrated a way of making optical computers practical for missile applications. There will be spin-off to other areas, including navigation and helicopter hover control. As we develop more sophisticated multichannel, multiplex devices, we expect to demonstrate fire and forget guidance for direct fire missiles.

ACKNOWLEDGEMENTS

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REFERENCES

1. J. G. Duthie, J. Upatnieks, C. R. Christensen, and R. D. McKenzie, Jr., "Real-time Optical Correlation with Solid State Sources", Proceedings SPIE, Vol. 232 (1980).

2. J. Grinberg, A. J. Jacobson, W. Bleha, L. Miller, L. Graas, D. Boswell, and G. Meyer, Opt. Eng. 14, 217-225 (1975).

3. W. P. Bleha, L. T. Lipton, E. Weiner-Avnear, J. Grinberg, P. G. Reif, D. Casasent, H. B. Brown, and B. V. Markevitch, Opt. Eng. 17, 371-384 (1978).

4. B. D. Guenther, C. R. Christensen, and Juris Upatnieks, IEEE J. Quant. Elec. QE-15, 1348-1362 (1979).

5. C. F. Hester and D. Casasent, Proceedings SPIE, Vol. 201, 77-82 (1979).

6. M. K. Hu, IRE Trans. Inform. Theory IT-8, 179-187 (1962).

7. W. T. Maloney, Appl. Opt. 10, 2127-2131 (1971).

8. K. G. Leib, R. A. Bondurant, S. Hsiao, R. Wohler, and R. Herold, Appl. Opt. 17, 2892-2899 (1978).

9. J. D. Armitage and A. W. Lohmann, Appl. Opt. 4, 461-467 (1965); see also A. Vander Lugt and E. N. Leith, Annals New York Acad. Sci. 157, 99-110 (1969).

10. J. Upatnieks, B. D. Guenther, and C. R. Christensen, "Real-time Correlation for Missile Terminal Guidance", US Army Missile Research and Development Command Technical Report H-78-5 (1978).

11. A. W. Lohmann, Appl. Opt. 7, 561-563 (1968).

12. O. I. Potaturkin, Appl. Opt. 18, 4203-4205 (1979).

13. A. W. Lohmann and H. W. Werlich, Appl. Opt. 10, 670-672 (1971).

14. J. Grinberg, W. P. Bleha, P. O. Braatz, K. Chow, D. H. Close, A. D. Jacobson, M. J. Little, N. Massetti, R. J. Murphy, J. G. Nash, and M. Waldner, Proceedings SPIE 128, 253-266 (1977).