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AN ON-BOARD SPACECRAFT OPTICAL DATA PROCESSING SYSTEM USING PARABOLOIDAL MIRROR SEGMENTS AND A GALLIUM ARSENIDE LASER

AKRAM S. HUSAIN ABIDI

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ABSTRACT

A compact and rugged optical system for on-board spacecraft is described. A G_a A_s laser is used as a source of coherent monochromatic source of radiation. Paraboloidal mirror segments are used as collimating, Fourier transforming and image reconstructing elements. The system is capable of performing a number of operations such as analysis in spatial frequency plane, single frequency filtering to remove coherent noise, spatial low frequency reduction to remove the effects of glare and pattern recognition and extraction. Some preliminary experimental results are presented.

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OBJECTIVE

The primary object of the work is to provide a compact on-board spacecraft optical data processor for a number of operations such as spectrum analysis, pattern recognition and spatial filtering.

PRIOR ART AND ITS DISADVANTAGES

Since 1873, when Abbe[1] demonstrated in his classical paper that the diffraction pattern in the focal plane of the lens has all the properties of the Fourier transform of the input information which is placed a focal length away from the lens, and also that spatial filtering can be achieved by blocking the appropriate portion of the diffraction pattern of a picture, lenses were exclusively used to produce the diffraction pattern in their focal planes.

The quality and resolution of Fourier transform relationship in the focal plane of the lenses is very much affected by the lens aberations and the optical refracting material. Among the aberations the following four are primarily responsible for the degradation of Fourier relationship:

(i) Spherical aberation

(ii) Chromatic aberation

(iii) Astigmatism

(iv) Coma

Beside overcoming these aberrations the other severe problem is the choice of the proper optical material. For an ultra-high quality lens suitable for data processing, the optical material should be:

(i) Optically homogeneous to a very high degree. (It is very important that the refractive index of the lens be constant throughout the material.)

(ii) Free from thermal and mechanical strains.

(iii) Optically Isotropic (i.e. the index of refraction at any point must be constant regardless of the direction in which the radiation is passing the point.

Therefore, for a good optical system with lenses it is necessary to rectify all the aberrations and one should also cope with the selection of proper optical material. Both of these problems are extremely difficult to rectify and costs are astronomical.

The other two disadvantages are the front surface reflections which are unavoidable and the axial symmetry of the system, (i.e. the optical system with lenses cannot be folded and therefore is a problem for spacecraft purposes).

ADVANTAGES OF THE PRESENT SYSTEM

The paraboloidal mirror segments used in the present optical system as the Fourier transforming component have the following advantages over lenses:

1. They are inherently free from spherical and chromatic aberations,
2. Absence of front surface reflections,
3. The optical system can be folded resulting in a considerable saving of space,
4. Astigmatism and Coma can be minimized to a far greater extent than in lenses, and finally
5. Since the light does not have to pass through the material of a front surface reflecting paraboloidal mirror, it is not necessary that optical material for fabrication purposes should be homogeneous and isotropic. Therefore, the use of paraboloidal mirrors overcomes all the critical optical material limitations.
6. The invention provides a method for performing optical data processing using electromagnetic waves of any frequencies. Lenses for ultra-violet infra-red and especially in radio frequencies are, if not impossible, very difficult to fabricate.

MODE OF OPERATION OF OPTICAL PROCESSOR

In Figure 1 the optical system is schematically illustrated. The coherent light source 1 is a p-n Gallium Arsenide laser with an effective radiating area of

3 mils. The laser operates at room temperature at a wavelength of 9000 A. It is placed in the focal plane of the paraboloidal mirror 4. The coherent monochromatic light 2 from G_a A_s laser 1 diverges and typically forms a 30° angle. The coherent light source is almost a point source and since it is in the focal plane of the paraboloidal mirror 4, the light reflecting from the paraboloidal mirror segment 3, (of mirror 4) is collimated.

To perform a two-dimensional spectrum analysis, the information to be analyzed is recorded on a transparency (either by taking the photograph or by electronically generating the object image). The transparency 6 is placed in the collimated beam 5 and is a focal length away from the paraboloidal mirror 7. The paraboloidal mirror segment converts the information of transparency 6 into a diffraction pattern that has all the properties of Fourier transform in the plane 10 centered at the point 9 which is the focal point of the paraboloidal mirror 7. The information in diffraction pattern can be converted into electrical signals by placing an appropriate photon detector 11 in the plane 10. The photon detector 11 could be of any suitable geometry such as in the form of wedges or concentric rings. This system satisfies the following two well-known facts:

a. "the Fraunhofer diffraction of an aperture is the two dimensional Fourier transform of the transmission function of that Aperture." and

b. "the Fourier transform of any function is independent of that function, (of course, with one exception which is the case for a linear phase factor).

Spatial filtering can be performed in the plane 10. For example, the two basic types of filtering, "band pass" and "band stop," can be achieved by having a transparent and an opaque region at a desired place in the plane 10. (Optical filters are normally in the form of wedges, annular ring or opaque disks and are placed in the plane 10.) The light transmitting through the filter/detector 11 is reflected by a paraboloidal mirror segment 13 of paraboloid 14 placed a focal length away from the plane 10. The transparency is reconstructed at the plane 15 which is a focal length away from the paraboloidal mirror 14.

Figure 2 shows the conceptual design of the system. It is planned that all three off-axis paraboloidal mirror segments will be carved within a block of some suitable material.

PERFORMANCE OF THE SYSTEM

Figure 3 shows the Fourier transform of a rectangular aperture. As it is well known the Fourier transform is centered at the optical axis and is in a direction orthogonal to the length of the rectangular. Figure 4 shows the Fourier transform of a circular aperture, the well known Airy disk can be seen distinctly in the center of the transform.

To prove the fact that the Fourier transform of a product of two functions is equal to the convolution of the Fourier transform of the two functions, let us consider the example of equally spaced parallel lines in a circular aperture. The Fourier transform of the combination will be the convolution of two individual transforms. The Fourier transform of a circular aperture is an Airy disk and the Fourier transform of parallel lines is a series of lines with separation inversely related to the spacing of the line and orthogonal to the direction of the lines; therefore, their resulting Fourier transform will be an Airy disk at the origin and also at the locations of each line. This is illustrated in figure 5 (a), (b). Figure 6 shows an example of spatial filtering. The Fourier transform of a triangle and its reconstructed image are shown in Figure 6 (a) and (b). To filter out one of the sides of the triangle a narrow wedge is placed in the Fourier transform plane, so that one of the components of the Fourier transform can be blocked. This is shown in Figure 6 (c). The reconstructed image is shown in Figure 6 (d). It can be seen that this reconstructed image is without one side. The missing side has been filtered in the Fourier transform plane.

CONCLUSION

The optical system presented here is very compact and rugged since it can be fabricated within a solid block of some suitable material such as silica or beryllium. The paraboloidal reflecting surfaces used as collimating, Fourier transforming and image reconstructing elements are by far superior to any other surfaces or elements used to perform such operations. It has been shown experimentally that spatial filtering can conveniently be performed by this system.

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The author is a "Postdoctoral Resident Research Associate" of National Academy of Sciences (U.S.A.).

REFERENCE

Abbe, Ernst, "Beitrage zur Theorie des Mikoskops und der mikrospopischen wahrnehmung." Archiv fur Mikroskipishe Anatomie, Vol. 9, pp 413-468, 1873.

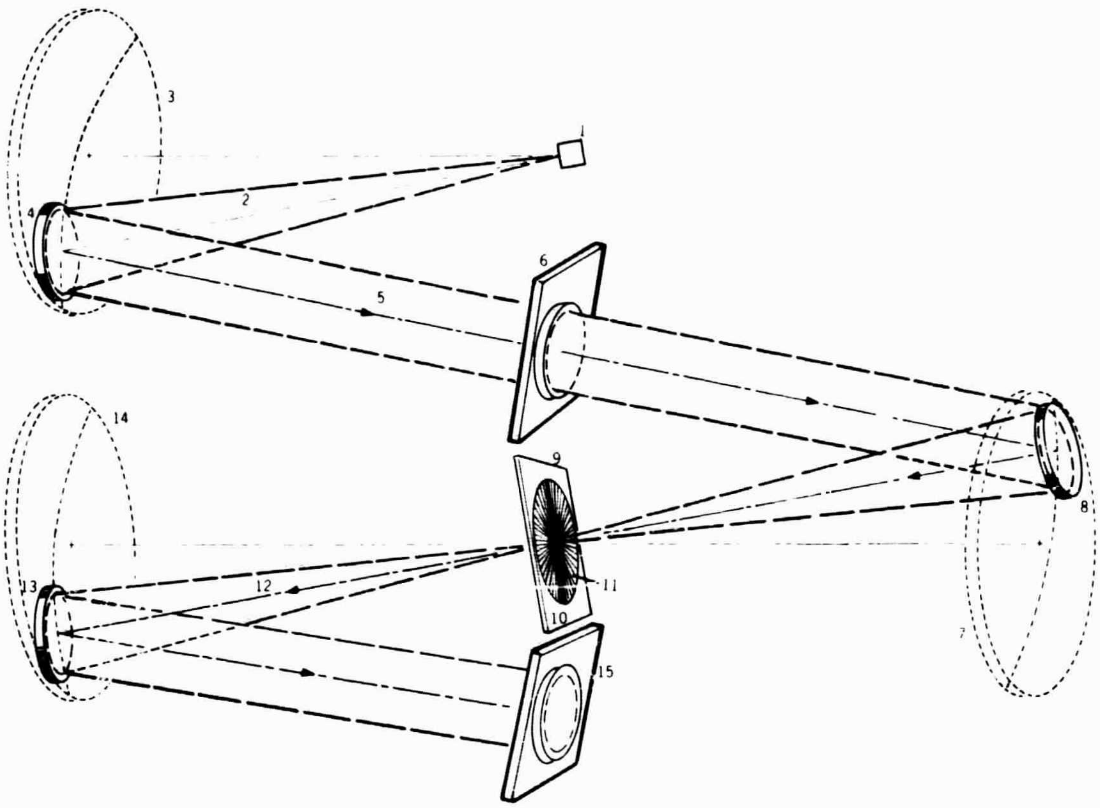

Figure 1. Optical Data Processor

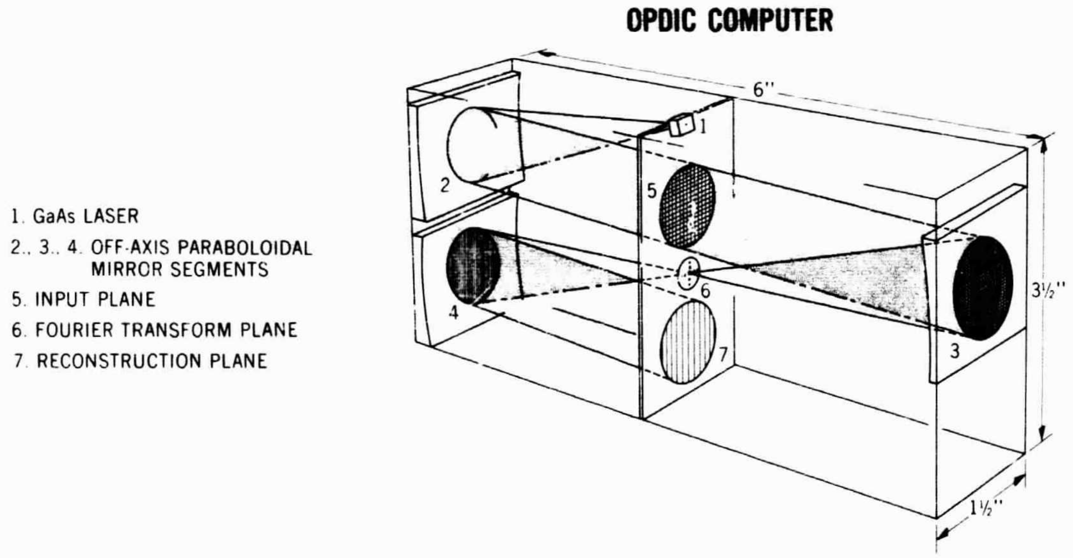

Figure 2. A Conceptual Design of The Optical System

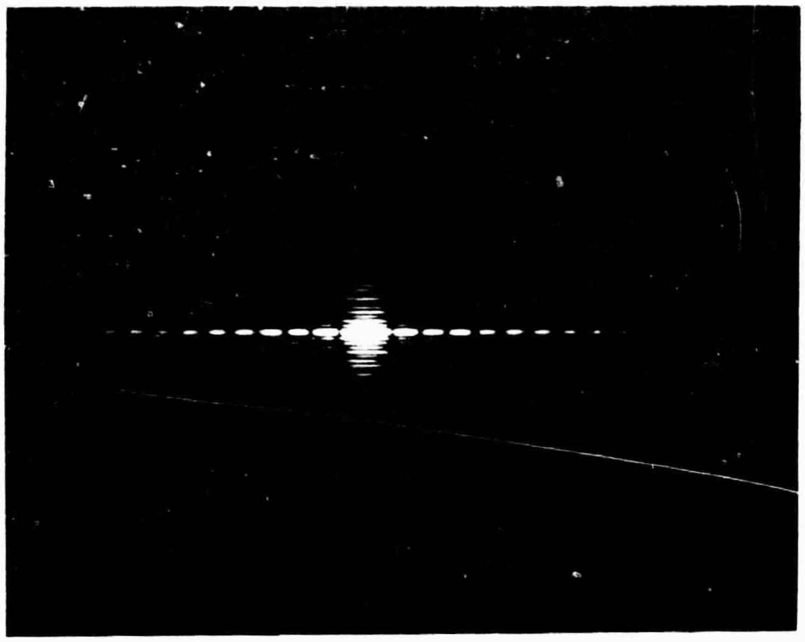

Figure 3. The Fourier Transform of a Rectangular Aperture

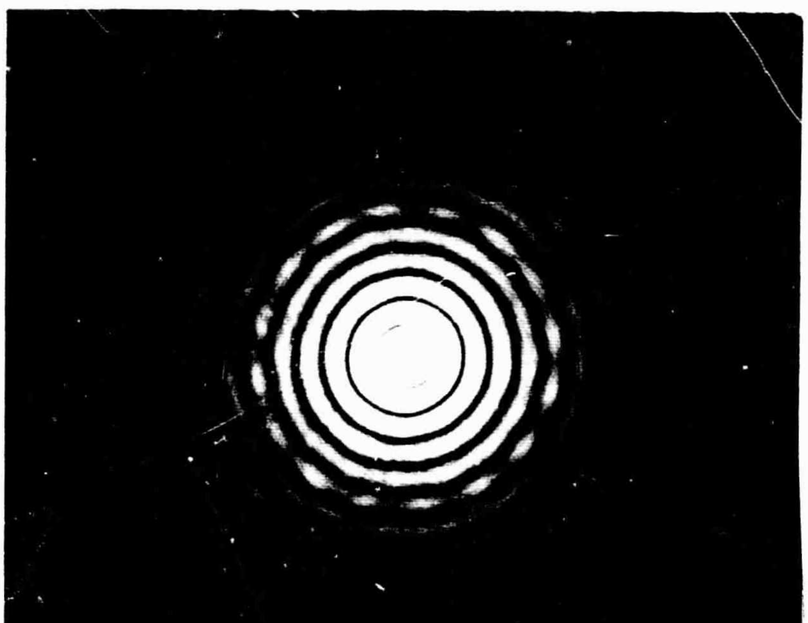

Figure 4. The Fourier Transform of a Rectangular Aperture

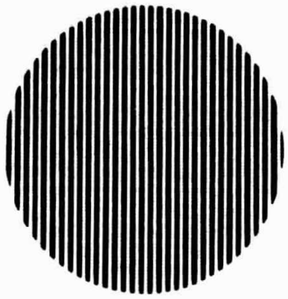

Figure 5(a). Equally Spaced Parallel Lines in a Circular Aperture

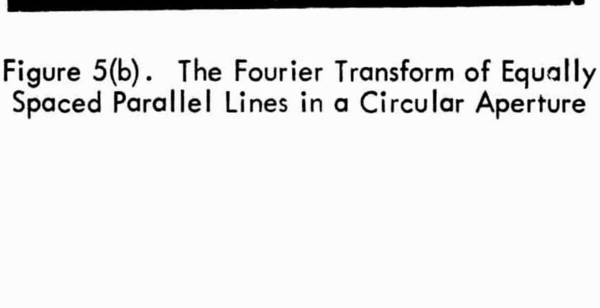

Figure 5(b). The Fourier Transform of Equally Spaced Parallel Lines in a Circular Aperture

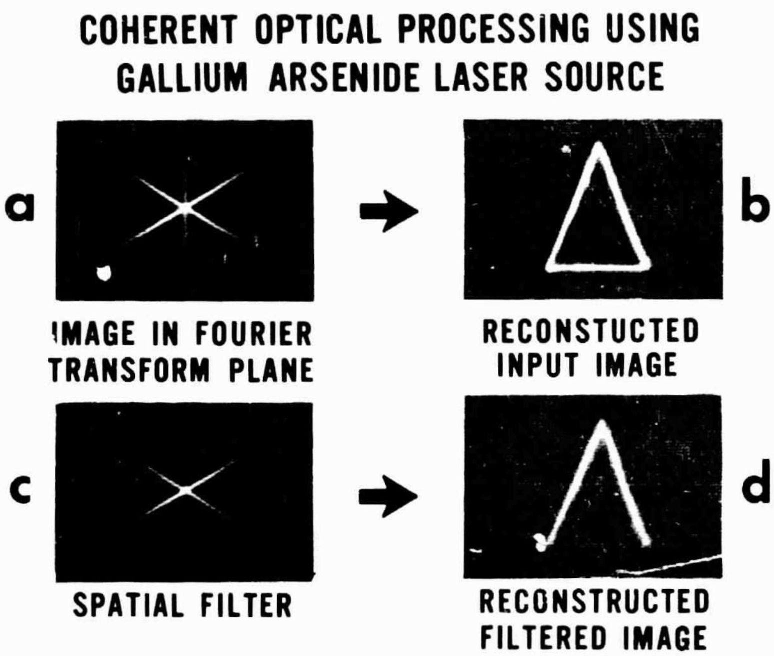

Figure 6. Spatial Filtering in Fourier Transform Plane