16.2 Industrial Pattern Inspection Using a Laser/Microprocessor System, T. Tanaka, Y. Hirakawa, Y. Marutani and I. Nagata, *Osaka Prefectural Industrial Research Institute, Osaka, Japan*

(*15* min)

A laser/microprocessor system is discussed that investigates the shape of industrial components to check for defects after correcting for shift and rotation of the object. This 2-dimensional image processor system, shown in Fig. 1, consists of a laser system and an electronic digital system. A 2-D Fourier transformation is first performed by the laser optics, and the comparison, normalization and decision-making are then carried out by the microcomputer. High-speed, flexible and economic shape inspection equipment for industrial pattern inspection has been built using this hybrid system.

The image of the object is illuminated with incoherent light and then converted to a coherent image through the incoherent-to-coherent image converter (ITC). A laser beam illuminates the image on the ITC and the Fourier-transformed image is obtained on the faceplate of the vidicon placed in the focal plane of lens L_2. The vidicon scans the image circularly, and the video-signal is stored in the memory. The object's rotation angle is determined and the stored data compared to the reference data in the microcomputer. It is also possible to measure the size of the object merely by changing the software.

Many methods exist for realization of the ITC; after considering the sensitivity, resolution and size, etc. requirements, a BSO ($Bi_{12}SiO_{20}$) single crystal was chosen. The BSO is covered by a transparent dielectric thin film and held between two transparent conductive plates. The limiting resolution of the ITC is about 100 lines/mm, its sensitivity is equivalent to ASA 100, the effective aperture is 10 × 10 mm (typical), and writing and erasing time is less than 1 msec. Fig. 2 shows the ITC (the part encircled by dashed lines in Fig. 1).

The vidicon placed in the Fourier plane serves as the interface between the laser optics and microcomputer. The Fourier plane is divided into 64 radial and 64 angular segments in a format. These 4096 Fourier plane samples are obtained and stored in 50 msec as 8 bit data, using a direct memory access channel. The microcomputer used consists of micro CPU chips with an 8-bit word length and a 2 μsec cycle time. A flow chart of the inspection procedure is shown in Fig. 3. Agreement between the input object and a stored reference is obtained by digital calculation of the correlation coefficients.

Fig. 4 shows examples of input objects examined [(a), (b)] and their Fourier-transformed images. From Fig. 4, we see that detection of a defect by inspection of the Fourier transform patterns (c), (d) is far easier than by direct comparison of the input objects (a), (b) themselves.

In this system, the correlation and decision-making are performed by the microcomputer system and the Fourier-transform by the optical system. Since the magnitude of the Fourier transform is shift-invariant, rapid inspection of objects is possible. Since the components used in this system are not expensive, the total system can be constructed economically.

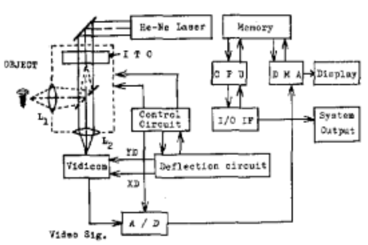

Fig. 1. Block diagram of the system.

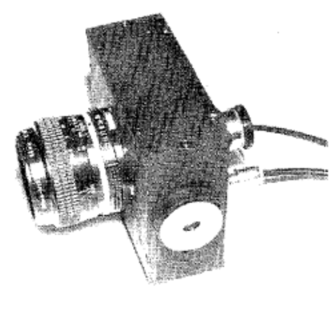

Fig. 2. Outside of the ITC.

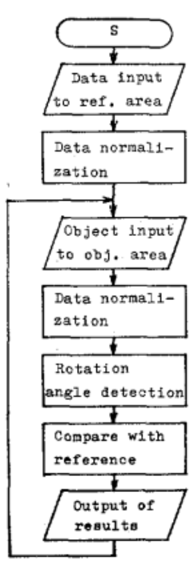

Fig. 3. Flowchart of the software for the inspection.

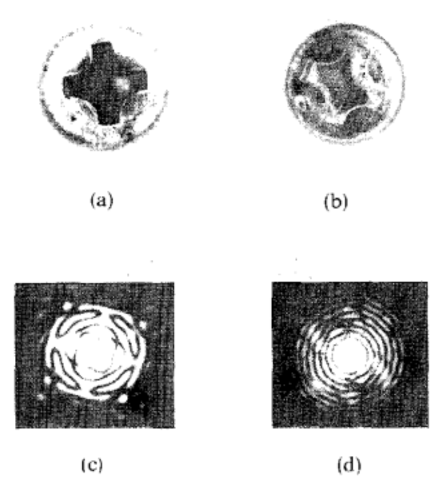

Fig. 4. Examples of input objects (the heads of screws). (a) No defect. (b) With defect. (c) F.-transformed image of (a). (d) F.-transformed image of (b).

16.3 Space Variant Optical Processors,[1] D. Psaltis, D. Casasent and A. Furman, *Department of Electrical Engineering, Carnegie-Mellon University, Pittsburgh, Pa. 15213*

(*15* min)

The lack of flexibility in an optical processor has been one reason for the slow maturing of such systems despite their large space bandwidth product and parallel processing capability. We specifically refer to the linear space invariance of an optical processor which has generally limited the operations achievable with such systems to the Fourier transform, correlation, and convolution. An extension of this repertoire of operations requires one to introduce space variance into the optical processor. In this paper, we consider the use of coordinate transformations as a convenient, powerful, and easily achieved method of realizing a space variant optical processor. We review our past work[2] in this area and present new results, emphasizing a wealth of diverse application areas for space variant optical processors.

We demonstrated earlier that the coordinate transformations required to produce a scale invariant optical processor could be implemented electronically by analog modules in the input scan system or optically in parallel by computer generated holograms. The operation realized is a Mellin transform, which is equivalent to the Fourier transform of the function f (exp ξ, exp η) where $f(x,y)$ is the input function and the required coordinate transformation is simply the log of the coordinates of the function. This formulation of the Mellin transform allows it to be easily synthesized in an optical system in which the Fourier transform operation is performed automatically by a lens.

If these log scaled input and reference functions are used in an optical correlator, one can perform pattern recognition on objects with no loss in signal-to-noise ratio, even if the scale of the input and reference objects differ. Examples of such optical scale invariant correlations will be presented and their application to pattern recognition noted.

[1] Research supported by the Office of Naval Research on contract NR 350-011, the Air Force Office of Scientific Research on grant AF 75-2851 and the Ballistic Missile Defense Advanced Technology Agency.

[2] D. Casasent and D. Psaltis, *Proc. IEEE*, Jan. 1977.

Another feature of such a Mellin correlation is that the location of the output correlation peak is proportional to the scale difference between the functions. This is especially useful in signal processing where the location of the output correlation peak is now proportional to the Doppler shift between the two signals being correlated.[3] Examples of this application will also be presented.

In this paper we also discuss two new applications for space variant optical processors. Much of the imagery that must be processed is actually non-vertical due to differences in the camera angles at which the two images were taken etc. As a result the object and image planes are not parallel. In this geometry there is a 1-D scaling of one image that is a function of the tilt angle of the imaging system. The axis along which the scaling occurs thus depends on the relative orientation of the object and imaging systems. Various scenarios appropriate for diverse specific situations will be discussed in which the orientation angle θ or the tilt angle ϕ are known. The required coordinate transformations are also discussed and examples shown of the successful correlation of full resolution non-vertical aerial imagery that could not be previously correlated.

Another new application for space variant optical systems is the correlation of functions that are parabolically distorted, e.g. $f_1(x) = f(x^a)$. In this case, an $x = \exp \xi$ transform converts the exponentiation into a scaling e.g. $f_1(\exp a\xi) = f_2(a\xi)$. When two parabolically distorted functions are correlated in a scale invariant system after the above input coordinate transformation, the intensity of the output correlation peak will be independent of the scaling and the distortion factor "a" can be found from the location of the peak. Examples of this application will also be presented.

[3] D. Casasent and D. Psaltis, *Appl. Opt.*, Sept. 1976.

16.4 Detection, Transmission, Recording and Reconstruction of Low Frequency, Heterodyne Holograms,[1] A. J. Decker,[2] Y-H. Pao and P. C. Claspy, *Department of Electrical Engineering and Applied Physics, Case Western Reserve University, Cleveland, Ohio 44106*

(*15* min)

The remote sensing, transmission, recording, and display of visual information using holograms continues to be a practical goal. The fundamental problem is that the communications channels for remote transmission of holograms are narrowband channels, whereas, the most convenient holograms have a high space-spatial bandwidth product. However, much of the essential visual information about any scene is intrinsically low spatial frequency information. One low frequency property is the visible surface detail of an object. That detail is represented by the slowly varying factors in the transmittance or reflectance of the object. By itself, that information can easily be handled by a narrowband channel in a reasonable amount of time.[3,4] High spatial frequency recording has been used to eliminate certain intrinsic problems of low frequency holography, e.g., the overlap of the virtual image with the real image and with waves diffracted from self-interference terms in the hologram. The successful development of narrowband transmission of holograms depends upon resolving these problems for a low frequency hologram and upon acquiring the proper equipment for detection and replication of the hologram. This paper describes such a system that uses available communications equipment.

In this system, a heterodyne technique is used to eliminate the self-interference terms of the object and reference beams in a low frequency hologram before the information is transmitted. Furthermore, the real image is eliminated from the hologram reconstruction.

The technique being used to separate the cross terms of the hologram from the self interference terms is heterodyne recording of the hologram[4] followed by high pass filtering. Electrooptic or acoustooptic modulation is used to introduce a frequency difference Δf between the object and reference beams. If Δf is greater than about $2f_0v_H$ where f_0 is the maximum spatial frequency of the object in the scan direction and v_H is the scan velocity, a signal sufficient for construction of a hologram is obtained. The hologram is detected by a commercially available image dissector in a commercially available camera.

A technique which can be used for the elimination of the real image employs a radial distortion of the hologram followed by modification of the reconstruction beam. For example, suppose that a two dimensional transparency is located at a distance d from a hologram recording plane and that a hologram of that transparency is recorded using a plane wave as a reference beam. If the hologram is magnified radially by the factor $\sqrt{2}$ and if this magnified hologram is then illuminated by a spherical wave originating from a source at a distance $2d$ from the hologram, a slightly magnified virtual image having small aberrations will appear at the location of the original transparency. The real image will appear at infinity.

These techniques can be adapted to handle wide angle views of extended objects. A hologram recording of a wide angle extended scene such that all parts of that scene can be viewed in three dimensions from a single viewing position has the highest frequency requirement. This requirement is intrinsic to the scene and independent of the use of off-axis reference beams or other contributors of high spatial frequencies. The transmission of such a scene is not an insurmountable problem, however. A series of narrow angle views, frames, or holograms can be transmitted sequentially. In lieu of a rapidly writable, reconstructable, and erasable recording medium, these holograms upon reception can be recorded on a film strip and presented to the eye in the manner of a rotating 360 degree hologram.

[1] This work has been supported by a grant from NASA Lewis Research Center.

[2] On leave from NASA Lewis Research Center, Cleveland, Ohio 44135.

[3] L. H. Enloe, J. A. Murphy and C. B. Rubinstein, *Bell Syst. Tech. J.*, vol. 45, p. 879, 1966.

[4] L. H. Enloe, W. C. Jakes, Jr. and C. B. Rubinstein, *Bell Syst. Tech. J.*, vol. 47, p. 1875, 1968.

16.5 Hologram Synthesis Using Photodichroic NaF Crystals in the In-Line Scheme, Y. Mitsuhashi and T. Morikawa, *Electrotechnical Laboratory, Tokyo 188, Japan* and M. Nakajima, M. Sahara and N. Okada, *Keio University, Yokohama, Japan*

(*15* min)

The concept of a computer-generated polarization hologram[1] (CPH) is based on the anisotropic interaction of light with photodichroic crystals. In the configuration incorporating a crystal-analyzer pair as shown in Fig. 1, one can realize arbitrary values of the bipolar amplitude transmittance, Tp, for a linearly polarized reading beam by controlling the polarization angle, θ, of a writing beam. This fact is well suited to synthesizing holograms in the in-line scheme.

We will describe an experimental verification of our CPH concept using photodichroic NaF crystals. The crystal plate used in the experiment as a hologram medium has a sensitive layer of 0.2 mm thickness with M centers therein. As a light source we used a Kr laser and tuned it to 351 nm for hologram writing and erasing, and to 521 nm for hologram reading.

Preliminary measurements were made to determine how Tp depends on θ for the crystal. A typical example of Tp-θ curves thus obtained is shown in Fig. 2. For this measurement, the diameter of the writing UV beam spot was about 0.06 mm and the exposure for each cell was 0.70 sec. The writing power density was about 1.2 W/mm^2.

With the help of this result, computed amplitudes $A \cos \phi$ for the digitized Fourier-transform

[1] M. Nakajima, H. Komatsu, Y. Mitsuhashi and T. Morikawa, *Appl. Opt.*, vol. 15, p. 1030, 1976.

Fig. 1. Optical arrangement for reading the computer-generated polarization hologram.