Guest Editorial

Optical And Digital Information Processing

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Long before the development of electrical systems and devices, optical systems were being used to perform the collection, transmission and storage functions of information processing. In recent years, the mathematical structure common to electrical signal analysis and optics has led to increased interaction between the two disciplines, with tremendous benefit to both. Optics has provided insight into the field of image processing by digital and electrical techniques, including image transmission and coding, image enhancement and restoration, and pattern recognition.¹⁻⁸ At the same time, the analysis and synthesis of optical systems and advances in microscopy, spectroscopy and interferometry have directly benefited from the insights of signal and communication theory mathematics.⁹⁻¹³

The very recent invention of holography¹⁴⁻²² and optical information processing^{9-13,23,25} and the development of hybrid systems combining electronic and optical components have followed this interaction.²³⁻²⁴ The purpose of this special issue of *Optical Engineering* is to present to our readers some of the current capabilities, applications and concepts of analog, digital or hybrid techniques to optical information processing. Due to the large volume of published work in the field, it is impossible to give even a short representative sample of individual papers in this guest editorial. Instead, several review articles, textbooks and bibliographies are listed. The papers in this special issue have been chosen to provide a spectrum of approaches and applications in the field. The authors have been asked to include additional de-

tailed background and reference material in their articles, and the omission of any references in this editorial or in the papers is unintentional.

This special issue begins with a paper by K. Campbell, G.W. Wecksung and C.R. Mansfield in which the removal of known degradations (image restoration) is accomplished by both digital computer techniques and by coherent-optical processing methods. The optical filters used are multilevel masks produced on photographic film by a high resolution plotting microdensitometer, and the holographic Vander Lugt method is used to encode amplitude and phase variations. The results obtained by these two methods are comparable and demonstrate the feasibility of using a computer and plotter to specify and generate precision masks that can be used in a relatively inexpensive optical processing system. The best aspects of both digital and optical processing are thus used to their advantage in such an arrangement. Optical processing has the advantage of speed, simplicity and low cost, with disadvantages of fixed system parameters and reduced precision. By comparison, digital processing offers easily changeable system parameters and high precision, but with the drawbacks of expensive, complex hardware and several slow intermediate operations of scanning and display of the image data.

The second paper by D.C. Chu and J.R. Fienup is concerned with some recent developments in computer generated holograms that make it possible to store complex amplitude and phase information directly without the nec-

essity of Vander Lugt or other spatial carrier frequency techniques used in optical holography. Their method utilizes the multilayer emulsions in ordinary color film to provide amplitude control by absorption of monochromatic light and phase control by thickness (delay) modulation of the nonabsorbing layer. The modulation transfer function (MTF) requirements of the film are greatly reduced, and the holograms are very efficient in their use of light because the display can be produced on-axis with no sidebands. Their work includes a discussion of kinoforms (phase-only holograms), applications to information processing and holographic memories, and references to holograms in optical testing and interferometry. The potential of their method is very significant because it reduces the requirements of the optical processing system, the display device for generating the hologram and the material on which the hologram is made. In addition to their use as a coherent-optical system element, these devices should also find application in incoherent optical systems. The flexibility and control inherent in computer holography permits the precise fabrication of exotic optical elements which could not be made previously with conventional techniques.

The article by S.H. Lee demonstrates the capabilities of optical processing for performing a number of specified mathematical functions. Image translation, addition, subtraction, integration, differentiation and linear operations can all be easily implemented with the introduction of various gratings and filters in a coherent optical system. Because of the inherent system linearity in complex amplitude, these and most other types of operations are all linear. It has been shown that image processing systems with nonlinear capabilities permit a much broader class of processing to be performed, giving superior results over purely linear processing. Some experimental digital verification of this has been reported with good results, and Lee's paper presents several optical processing techniques which use nonlinear devices and elements. These devices are used as multipliers in the spatial frequency plane for a new type of optical filtering, and for the synthesis of nonlinear characteristic curves for contrast enhancement. His paper also includes results from a novel optical feedback processor, which is analogous to electrical feedback systems. Combining the feedback system with linear and nonlinear elements improves the dynamic range and flexibility. Image restoration, contrast enhancement and analog computations in the solution of partial differential equations are demonstrated. Once again, the interaction between optics and electronics has stimulated the development of optical systems which perform a wide variety of information processing functions.

The next two papers discuss the application of optical processing in two more-specialized areas. G.A. Krusos describes the coherent processing of X-ray images (radiographs) to remove the blur resulting from finite source size. Both analog and digitally-generated optical elements are useful for this type of filtering, and further developments in this area should significantly improve the quality of medical imaging. The paper by T.C. Strand considers signal and noise relationships in digital holography and provides a comparison of binary holograms versus continuous-level holograms. This work is important in the design of holographic memories where extreme accuracy is necessary. In any information processing or storage system, noise, as either measurement or fabrication errors, ultimately becomes a limiting factor. Binary holograms are shown to have certain advantages in some applications because they are easily reproduced and are

more immune to film-grain noise.

D. Casasent next presents a hybrid optical/digital system which combines the best elements of both techniques. The system accepts electrical signals which are introduced onto an electron-beam addressable light modulator in real time. A Fourier transform optical processor provides fixed or variable filtering operations at high speed, and output information is available optically or digitally. The system operates under computer control and performs filtering and transforming operations on optical and electrical information. The paper includes applications to radar signal processing and a detailed comparison of electrically and optically addressable light modulation devices.

The future practical use of hybrid systems depends greatly on the development of electrical-to-optical and optical-to-electrical transducers. S. Iwasa and J. Feinleib describe a Pockel's readout optical modulation device (PROM) which is controlled by a combination of optical and electrical techniques. The device has the resolution necessary for optical processing applications, and can perform certain enhancement and nonlinear operations directly on the input data under electrical control. Applications involving filtering, correlation and optical memories are demonstrated in a typical configuration for optical processing. The papers by H. Stark and by E.L. Hall, R.P. Kruger and A.F. Turner also consider hybrid information processing systems of a special purpose nature. The arrangement described by Stark consists of a coherent optical system which preprocesses input image data by transforming, masking or filtering. This is followed by a television system for gray level measurements, outlining, and pseudocolor enhancement of selected features. A human interactive observer can make measurements and control the processing function, and the optical processing easily accomplishes a data reduction which would be costly and complicated for a digital system. The system described by Hall, Kruger and Turner uses a digital scanning system to automatically position an input transparency within a coherent-optical Fourier transform system. A special purpose detector is used to sample the transform, and pattern classification decisions are made by a minicomputer system from these optical measurements. Their hybrid approach is used to screen chest radiographs for abnormalities as an aid to the diagnosis of lung disease. In both of these systems, optical processing serves as a many-to-few mapping which tremendously reduces the available data for machine or human classification without destroying the essential information. Both papers discuss additional applications in photointerpretation, scene analysis and cloud identification. Results from this particular approach to optical processing have been very promising, and active research is underway to find different types of optical transformations to extend the capabilities of the technique.

J.F. Walkup and R.C. Choens next present a discussion of noise effects and limitations in optical and digital processing, and outline some filtering techniques for noise suppression. They review some of the classical Wiener filter methods and develop a detailed model for film-grain noise effects. By accounting for the signal-dependent nature of film-grain noise, modified filtering methods are derived which reduce the error of pure Wiener filtering. Their work can be implemented by digital processing or by analog or digital optical holographic filters of the type discussed earlier in this editorial. They point out the need for additional work in film-grain noise because of the limitations and inadequacies of present models, and the almost universal use of photographic film as a storage

and modulation medium in optical processing.

The last contribution is by W.T. Rhodes, who describes a new synthetic-aperture technique for high resolution optical imaging. His method combines digital processing with optical data collection in a small aperture system to achieve wide spatial frequency bandwidth and reduced system aberrations. The processing technique allows reduced tolerances on the optical alignment and positioning since compensation of the optical transfer function (OTF) can be implemented digitally.

Even though these papers show considerable development from early research in optical processing, there are several areas in which a great deal of work remains. Some of these areas include: processors for realization of nonlinear functions; development of input and output electro-optical transducers with high sensitivity, large space-bandwidth product and fast, controllable response; and linear space-variant processors to perform operations which vary as a function of position. Although optical processing systems may never approach the precision and generality of the digital computer, their advantages for accomplishing many practical functions are now being realized. In the near future, it is expected that a number of commercial systems for special purpose optical processing will become available. In conclusion, it is hoped that the philosophy and methods of optical processing described in this special issue of *Optical Engineering* will encourage future investigation and development of the subject.

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