OPTICAL SIGNAL PROCESSING

Edited by JOSEPH L. HORNER

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Preface

It would be difficult to say just when the field of optical signal processing had its inception. Certainly the birth of the laser and the discovery of off-axis holography in the early 1960s got the field off to a running start. In the intervening years the field has seen several cycles of bloom and doom. Right now there seems to be a resurgence of interest and support for optical systems and devices as solutions to recurring technological problems.

There have always been two basic characteristics of our field. First, it is a hybrid technology, and second, it has been a practical field, proposing solutions, as opposed to developing even deeper and more encompassing theories. It is a hybrid in that it has utilized the tools, theories, and techniques from many diverse disciplines—physics, mathematics, engineering, and chemistry. This is also reflected in our academic training: some of us come from the physical sciences and some from the engineering sciences.

This book is in a sense a microcosm of all these facets. I have tried to get researchers from many different areas of optical signal processing to write synopses of their current work. It is also, by and large, a practical book, in which systems or algorithms that have been successfully tried and used are described. This book will be of special interest to workers and researchers in this field, students at a senior or graduate level, scientific administrators, and scientists and engineers in general.

I would like to thank the contributors and dedicate this book to them; most of the contributors are colleagues and friends whom I have known since the late 1960s, as we have matured (real meaning: grown old) together as the field has developed. I especially want to thank H. John Caulfield, Director of the Center for Applied Optics at the University of Alabama, Huntsville. Early on he encouraged and stimulated my interest in editing this book. I also thank my editors at Academic Press for their patience, help, and advice.

We all hope this book will be a useful addition to a growing field, which is still in the process of realizing its full and rightful potential.

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I

White-Light Processors

1.1

Color Image Processing

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I. Introduction

Although coherent optical processors can perform a variety of complicated image processings, coherent processing systems are usually plagued with annoying coherent artifact noise. These difficulties have prompted us to look at optical processing from a new standpoint and to consider whether it is necessary for all optical processing operations to be carried out by coherent sources. We have found that many optical processings can be carried out using partially coherent light or white-light sources (Lohmann [1], Rhodes [2], Leith and Roth [3], Yu [4], Stoner [5], and Morris and George [6]). The basic advantages of white-light optical processing are (1) it can suppress the coherent artifact noise; (2) the white-light sources are usually inexpensive; (3) the processing environmental factors are more relaxed, for instance, heavy optical benches and dust free rooms are not required; (4) the white-light system is relatively easy and economical to

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operate; and (5) the white-light processor is particularly suitable for color image processing.

II. White-Light Optical Processing

An achromatic partially coherent processor that uses a white-light source [7] is shown in Fig. 1. The white-light optical processing system is similar to a coherent processing system except for the following: It uses an extended white-light source, a source-encoding mask, a signal-sampling grating, multi-spectral band filters, and achromatic transform lenses. For example, if we place an input object transparency $s(x, y)$ in contact with a sampling phase grating, the complex wave field, for every wavelength λ, at the Fourier plane P_2 would be (assuming a white-light point source)

$$E(p, q; \lambda) = \iint s(x, y) \exp(ip_o x) \exp[-i(px + qy)]\, dx\, dy$$
$$= S(p - p_o, q) \tag{1}$$

where the integral is over the spatial domain of the input plane P_1, (p, q) denotes the angular spatial frequency coordinate system, p_o is the angular spatial frequency of the sampling phase grating, and $S(p, q)$ is the Fourier spectrum of $s(x, y)$. If we write Eq. (1) in the form of a spatial coordinate system (α, β), we have

$$E(\alpha, \beta; \lambda) = S\left(\alpha - \frac{\lambda f}{2\pi} p_o, \beta\right) \tag{2}$$

where $p = (2\pi/\lambda f)\alpha$, $q = (2\pi/\lambda f)\beta$, and f is the focal length of the achromatic transform lens. Thus we see that the Fourier spectra would disperse into rainbow color along the α-axis, and each Fourier spectrum for a given wavelength λ is centered at $\alpha = (\lambda f/2\pi)p_o$.

In complex spatial filtering, we assume that a set of narrow spectral band complex spatial filters is available. In practice, all the input objects are

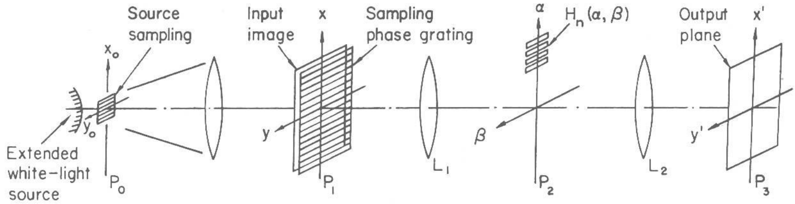

Fig. 1. White-light optical signal processor.

spatial frequency limited; the spatial bandwidth of each spectral band filter $H(p_n, q_n)$ is therefore

$$H(p_n, q_n) = \begin{cases} H(p_n, q_n), & \alpha_1 < \alpha < \alpha_2 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where $p_n = (2\pi/\lambda_n f)\alpha$, $q_n = (2\pi/\lambda_n f)\beta$, λ_n is the main wavelength of the filter, $\alpha_1 = (\lambda_n f/2\pi)(p_o + \Delta p)$ and $\alpha_2 = (\lambda_n f/2\pi)(p_o - \Delta p)$ are the upper and lower spatial limits of $H(p_n, q_n)$, and Δp is the spatial bandwidth of the input image $s(x, y)$.

Since the limiting wavelengths of each $H(p_n, q_n)$ are

$$\lambda_l = \lambda_n \frac{p_o + \Delta p}{p_o - \Delta p} \quad \text{and} \quad \lambda_h = \lambda_n \frac{p_o - \Delta p}{p_o + \Delta p} \tag{4}$$

its spectral bandwidth can be approximated by

$$\Delta\lambda_n = \lambda_n \frac{4p_o\,\Delta p}{p^2 - (\Delta p)^2} \simeq \frac{4\,\Delta p}{p_o}\lambda_n \tag{5}$$

If we place this set of spectral band filters side by side and position them properly over the smeared Fourier spectra, the intensity distribution of the output light field can be shown to be

$$I(x, y) \simeq \sum_{n=1}^{N} \Delta\lambda_n\,|s(x, y; \lambda_n) * h(x, y; \lambda_n)|^2 \tag{6}$$

where $h(x, y; \lambda_n)$ is the spatial impulse response of $H(p_n, q_n)$ and $*$ denotes the convolution operation. Thus the proposed partially coherent processor is capable of processing the signal in complex wave fields. Since the output intensity is the sum of the mutually incoherent narrowband spectral irradiances, the annoying coherent artifact noise can be suppressed. It is also apparent that the white-light processor is capable of processing color images since the system uses all the visible wavelengths.

III. Source Encoding and Image Sampling

We now discuss a linear transform relationship between the spatial coherence (i.e., mutual intensity function) and the source encoding [8]. Since the spatial coherence depends on the image-processing operation, a more relaxed coherence requirement can be used for specific image-processing operations. Source encoding is to alleviate the stringent coherence requirement so that an extended source can be used. In other words, source encoding is capable of generating appropriate spatial coherence for a specific image-processing operation so that the available light power from the source can be more efficiently utilized.

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