GRAPHICAL and BINARY IMAGE PROCESSING and APPLICATIONS

J.C. Stoffel

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To Christopher and Matthew with the hope that they have the opportunity in their time to work within as productive and stimulating an environment as that created by the contributing authors in this book.

The author wishes to express his sincere thanks to all the contributing authors who helped to make this book as rich a survey as it became. This is a growing field, and it's a pleasure to have worked with the supportive team whose articles are included in this book.

Especial thanks are due O. Schade, Jr., Ralph Ciafone of RCA Princeton Labs, and P. Wheeler of Bell Labs for their assistance in enabling republication of the classic work of O. Schade, Sr., P. Mertz, and F. Gray.

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chapter 1

INTRODUCTION

Graphical and Binary Image Processing and Applications is a collection of published research and tutorial articles for three classes of readers. The first set of intended readers includes engineering and computer science researchers and students focusing attention on the major topics in image processing for two-tone binary images. Both the fundamentals and recent research are included.

The second group of potential readers includes the applications engineer and systems designers. Articles describing practical algorithms, tradeoff studies, international standards, and specific applications are included.

The third group of potentially interested readers are managers. Electronic information systems for publishing, reprographics, office information, CAD, and archival applications utilize binary imagery as the primary venue for human interface. Consultants, technical program managers, and executives can gather needed insight into what can be done, how complex the solutions are, and who is active in these areas from a review of this book.

This text does *not* cover classical computer graphics or image pattern recognition, but focuses on scanned imaging systems. Therefore, the content of the book begins with a tutorial level presentation on electronic scanning fundamentals, including analytic treatments of the nonlinearities of binary signal generation from scanned imagery. The models are useful for statistical studies and design optimizations. Next is a description of quality metrics appropriate for binary imagery. Again one often needs metrics for system (design) optimization, and there is no universally appropriate image quality metric. Recent and varied metrics are included to assist the reader with their particular needs.

The next chapter contains recent tutorial and tradeoff study reports by researchers concerning the methods of line copy (text and graphics) detection and discrimination from background. These smart thresholding studies are followed by a complementary chapter on pictorial reproduction techniques. Both continuous tone and halftone input are considered, and algorithms compatible with laser xerographic printers, photolithography, plasma display panels, binary mode CRT's inkjet and other two-tone marking processes are presented.

Efficient systems designs imply a necessity for redundancy reduced encoding of imagery. Chapter seven reviews the most efficient, state of the art encoding techniques for binary imagery, including line copy and pictorials. A review of recent international standards and the most likely future directions is also included.

Chapters eight and nine deal with image manipulation. Chapter eight focuses on "signal/noise" enhancement techniques for binary imagery, and the following chapter reviews techniques appropriate for magnifying and reducing an image once it is in a binary format.

The last chapter contains example applications of some of the aforementioned techniques to real world problems. The applications include a computer vision inspection problem for manufacturing circuit boards, a printed character copy quality analyzer, a CAD (engineering drawing) system, a newspaper communication system, a laser platemaking system, and a page composition system for a broad range of reprographics. Productivity in the "factory" and the "office" is the goal of today's binary imaging systems applications; this chapter cites a few of the important attempts in recent years.

The application of signal processing theory and technology to imagery has become very practical within the last ten years. For this reason image processing has become an active area of research, and a number of books have been published addressing grayscale image encoding, enhancement, restoration, and other problems. Also, a good deal of research is being done on two-tone (black and white) imagery, but this is primarily scattered throughout a variety of journals, proceedings, and the patent literature. Therefore, this book attempts to coalesce a number of the key disclosures describing two-tone, binary image processing research and application. Furthermore, this book takes the form of a collection of reprints, since the time consuming production of a textbook would inhibit communicating the recent insights presented in the reprint format.

Unfortunately, not all of the excellent work in the topical areas discussed below can be included in this book, but efforts were made to collect works which span the range of research and application topics and have been published, for the most part, within the last five years. Thus, included with each chapter are relevant references which merit special attention. Also, key bibliographies and text references are included at the end of this chapter for those seeking further depth.

Especial thanks are given to the authors who have contributed their work to this book. It has been a pleasure working with them and their technical innovations.

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chapter 2

ELECTRONIC IMAGING SYSTEM FUNDAMENTALS

Throughout the rest of this book, sampled image processing and manipulation will be discussed. It is fundamental to that processing that there is both an input and output transduction process that represents the capture and manifestation of these images. This chapter, therefore, contains a collection of references dealing with the key features of electronic scanning systems as a background for the remaining chapters.

Considerable scanning systems activity has resulted in a multiplicity of input and output transducers for scanned imagery. CCD technology coupled with photodiodes has complemented well the input scanning technology arsenal, which has long included CRT flying spot and laser scanners, along with the graphic arts' drum scanners. The output scanning systems include CRT displays, flying spot printers, film drum scanners, laser scanners/printers, plasma panels, and ink jet printers. Virtually all of these are "binary markers" with their predominant mode of operation yielding either black or white pixels.

The remainder of the chapters in this book deal primarily with binary imagery that is generated from either continuous tone or essentially binary input. Continuous tone imagery is that class of imagery containing multiple gray levels with no perceptible quantization. Example images in this class include natural scenes as viewed through a TV camera or a photograph scanned on a facsimile transmitter. On the other hand, the "binary input" is most often represented by line copy, or half tone pictorial imagery on printed documents. Line copy refers to the graphics and characters that make up most of the printed material we read. Halftone input is composed essentially of white or black microstructure at a resolution which creates an apparent grayscale image at normal viewing distances. (For a better insight into the characteristics of halftone imagery, see Stoffel (1981) in Chapter 6.) This chapter, therefore, is an introduction to electronic scanning systems which form the input and output for the processors whose algorithms are reviewed in the subsequent chapters.

One of the earliest and most well written introductions to input and output scanning systems is the work of Mertz and Gray (1934). This work is fundamental to television, facsimile, and virtually all electronic imaging systems. It is the first article included below.

As a complement to the analytic perspective on scanning systems, the work of Schade (1948) provides an overview of the characteristics of the "hardware" often utilized in electro-optical imaging systems. His four part review in 1948 included the characteristics of the human visual system as well as electro-optical systems. In this chapter, Schade's work describing electronic camera systems is included.

To extend the work of Mertz and Gray, Robinson (1973) and Kermisch (1975) have provided analytic insight into the unique scanning problems for pictorial reproduction. This pair of papers provides further analytic insight into the spectral characteristics of scanned imagery, especially halftone pictorial representation. These motivate some of the complex signal processing discussed in Chapter 6.

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2.1 P. Mertz and F. Gray, "A Theory of Scanning and its Relation to the Characteristics of the Transmitted Signal in Telephotography and Television," *Bell System Technical Journal,* Vol. 13, 1934.

2.2 O. Schade, "Electro-optical Characteristics of Camera Systems," *RCA Review,* Vol. 9, 1948.

2.3 A. Robinson, "Multidimensional Fourier Transforms and Image Processing with Finite Scanning Apertures," *Applied Optics,* Vol. 12, No. 10, 1973.

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A Theory of Scanning and Its Relation to the Characteristics of the Transmitted Signal in Telephotography and Television

2.1

P. Mertz and F. Gray

The Bell System Technical Journal, Vol. 13, July 1934, pp. 464-515.

By the use of a two-dimensional Fourier analysis of the transmitted picture a theory of scanning is developed and the scanning system related to the signal used for the transmission. On the basis of this theory a number of conclusions can be drawn:

1. The result of the complete process of transmission may be divided into two parts, (*a*) a reproduction of the original picture with a blurring similar to that caused in general by an optical system of only finite perfection, and (*b*) the superposition on it of an extraneous pattern not present in the original, but which is a function of both the original and the scanning system.
2. Roughly half the frequency range occupied by the transmitted signal is idle. Its frequency spectrum consists of alternating strong bands and regions of weak energy. In the latter the signal energy reproducing the original is at its weakest, and gives rise to the strongest part of the extraneous pattern. In a television system these idle regions are several hundred to several thousand cycles wide and have actually been used experimentally as the transmission path for independent signaling channels, without any visible effect on the received picture.
3. With respect to the blurring of the original all reasonable shapes of aperture give about the same result when of equivalent size. The sizes (along a given dimension) are determined as equivalent when the apertures have the same radius of gyration (about a perpendicular axis in the plane of the aperture).
4. With respect to extraneous patterns certain shapes of aperture are better than others, but all apertures can be made to suppress them at the expense of blurring. An aperture arrangement is presented which almost completely eliminates extraneous pattern while about doubling the blurring across the direction of scanning as compared with the usual square aperture. From this and other examples the degradation caused by the extraneous patterns is estimated.

IN the usual telephotographic or television systems the image field is scanned by moving a spot or elementary area along some recurring geometrical path over this field. In the more common arrangement this path consists simply of a series of successive parallel strips. Imagining the path developed or straightened out (or in the more common case, the strips joined end to end), this method of scanning is equivalent to transmitting the image in the form of a long narrow strip.

The theoretical treatment of such transmission has usually been developed by completely ignoring variations in brightness across the image strip, assuming the brightness to have a uniform distribution across this strip. This permits the image to be analyzed as an ordinary one-dimensional or single Fourier series (or integral) along the length of the strip; and the theory is then developed in terms of the one-dimensional steady state Fourier components. Such a method of treatment naturally gives no information in regard to the reproduction or distortion of the detail in the original image across the direction of scanning, nor, as will appear below, does it give any detailed information in regard to the fine-structure distribution of energy over the frequency range occupied by the signal.

The need of a more detailed theoretical treatment originally arose in connection with studies of the reproduction of detail in telephotographic systems, especially in comparisons of distortion occurring along the direction of scanning with that across this direction. Later, this same need was strikingly shown by the discovery that a television signal leaves certain parts of the frequency range relatively empty of current components. Certain considerations indicated that a large part of the energy of a signal might be located in bands at multiples of the frequency of line scanning. Actual frequency analyses more than confirmed this suspicion. The energy was found to be so closely confined to such bands as to leave the regions between relatively empty of signal energy.

Such bands and intervening empty regions are illustrated by the examples of current-frequency curves in Fig. 1. These curves were taken with the various subjects as indicated, and the television current was generated by an apparatus scanning a field of view in 50 lines at a rate of about 940 lines per second. The energy is grouped in bands at multiples of 940 cycles and the regions between are substantially devoid of current components. In addition to the bands shown by the curves, it is known that similar bands occur up to about 18,000 cycles and that there is also a band of energy extending up from about 20 cycles.

Certain of the relatively empty frequency regions were also investigated by including a narrow band elimination filter in a television circuit. The filter eliminated a band about 250 cycles wide and was variable so that the band of elimination could be shifted along the frequency scale at will. By shifting the region of elimination along in this manner it was found that a band about 500 or 600 cycles wide could be removed from a television channel between any two of the current components without producing any detectable effect on the reproduced image.

At a later date a 1500-cycle current suitable for synchronization was introduced into a relatively empty frequency region, transmitted over the same channel with a television current, and filtered out—all without visibly affecting the image.

These results indicated quite clearly the need of a more complete

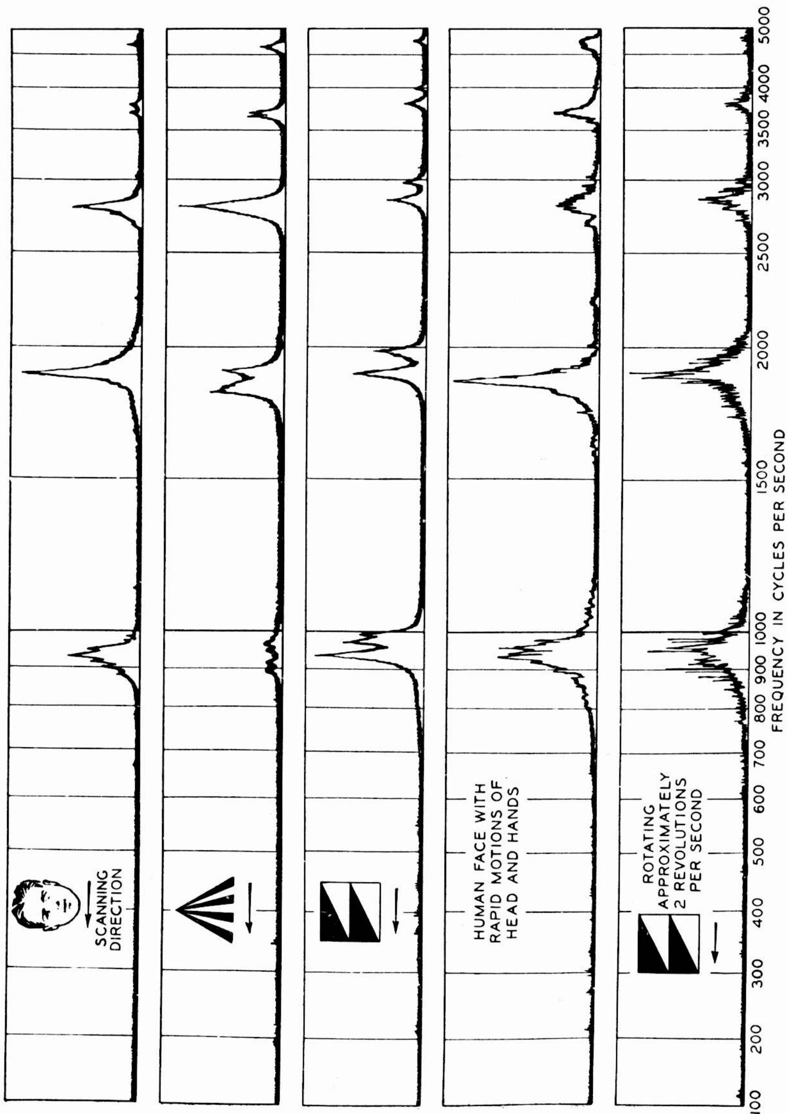

Fig. 1—Frequency analyses of television currents.

theory of the scanning processes used in telephotography and television and led to the study outlined in the following pages. Since this study will be confined to characteristics of the scanning processes all other processes in the system, wherever used, will be assumed to be perfect and cause no distortion.

The general trend of this more complete theory can be foreseen when it is considered that to obtain an adequate reproduction of the original it is necessary to scan with a large number of lines as compared with the general pictorial complexity of this original. This means that for any original presenting a large scale pattern (as distinguished from a random granular background) the signal pattern along successive scanning lines will, in general, differ by only small amounts. Thus, the signal wave throughout a considerable number of scanning lines may be represented to within a small error by a function periodic in the scanning frequency. Since such a function, developed in a Fourier series, is equal to the sum of sine waves having frequencies which are harmonics of the scanning line frequency, it will be natural to expect the total signal wave to have a large portion of its energy concentrated in the regions of these harmonics.

Furthermore, the existence of signal energy at odd multiples of half the scanning frequency will indicate the existence of a characteristic in the picture which repeats itself in alternate scanning lines. It is to be expected that such detail in a picture cannot be transmitted without accurate registry between it and the scanning lines and that when the detail spacing or direction or both differ somewhat from the scanning line spacing and direction, beat patterns between the two will be produced in the received picture which may be strong enough to alter considerably the reproduction of the original.

These phenomena are exactly what is observed, and will be treated in more quantitative fashion in the discussion below.[1]

An Image Field as a Double Fourier Series

Let us first consider the usual expression of the image field as a single Fourier series. The picture will be considered as a "still" so that entire successive scannings are identical. Then if the long strip corresponding to one scanning extends from $-L$ to $+L$, the illumina-

[1] In the following treatment an effort has been made to confine the necessary mathematical demonstrations almost exclusively to two sections entitled, respectively, "Effect of a Finite Aperture at the Transmitting Station," and "Reconstruction of the Image at the Receiving Station." Even in these sections a number of conclusions are explained in text which do not require reading the mathematics if the demonstrations are taken for granted. The occasional mathematical expressions occurring in the earlier sections are very largely for the purpose of introducing notation.