Digital Picture Analysis

Edited by A. Rosenfeld

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Preface

The rapid proliferation of computers during the past two decades has barely kept pace with the explosive increase in the amount of information that needs to be processed. The processing of pictorial information, obtained from both business and scientific sources, presents an especially challenging problem. Computers have found extensive use in tasks such as

a) Making weather maps from meteorological satellite television images, or land use maps from earth resources aircraft or satellite imagery;
b) Diagnosing pathological conditions by analyzing medical X-rays or microscope slides;
c) Searching for new fundamental particles by analyzing photographs of interactions in nuclear particle studies;
d) Reading handwritten or printed documents — zip codes on envelopes, credit card numbers on sales slips, etc.

This book contains review papers on the computer analysis of pictorial information in five major areas: remote sensing of the environment (via images obtained by aircraft or satellites); medical radiology; high-energy physics; cytology; and character recognition. The papers are written by recognized experts in these fields. Taken collectively, they provide a broad introduction, from a practical standpoint, to the important topic of digital picture analysis.

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Contents

1. Introduction

A. Rosenfeld

Modern high-speed computers can execute millions of instructions per second, but their capacity as information-processing devices is limited by the types of input data that they can accept, Much of the information that we might like our computers to process is in pictorial form; this includes alphanumeric characters (printed text, handwriting, etc.) as well as photographs and television images. Alphanumeric data can be manually converted into computer-readable form, but much faster input rates can be achieved if scanning and optical character recognition techniques are used. Photographs and images can be scanned and digitized, but it is still necessary to program the computer to analyze and interpret them automatically.

This book deals with the computer analysis of pictorial information. Each of the five chapters covers a different field of application, and is written by a recognized expert in the field. The application areas covered are

Remote sensing (Chapt. 2).
Radiology (Chapt. 3).
High-energy physics (Chapt. 4).
Cytology (Chapt. 5).
Character recognition (Chapt. 6).

Each of these areas has had specialized conferences or workshops devoted to it—in some cases, long series of them. Each has a large literature; see the individual papers for introductions to these literatures. Efforts have also been made to bring the different application areas closer together; examples of this include the Symposium on Automatic Photointerpretation, held in 1967 [1.1]; the NATO Summer Institute on Automatic Interpretation and Classification of Images, in 1968 [1.2]; the Special Issue of the IEEE Proceedings devoted to Digital Pattern Recognition, which appeared in 1972 [1.3]; and the U.S.-Japan Seminar on Picture and Scene Analysis, held in 1973 [1.4]. In addition, the many conferences on pattern recognition have included a wide variety of picture analysis applications.

Not all of the literature on computer analysis of pictures is application-oriented; over the past twenty years, a large body of generalpurpose digital picture analysis techniques has been built up. A summary of this material as of the late 1960's may be found in a textbook written by the editor [1.5]; a more recent book, which also covers three-dimensional scene analysis, is [1.6]. The editor has also written a series of survey papers [1.7–11] which cover much of the English-language literature in the field. He has recently co-authored a more comprehensive textbook, treating digital picture processing and analysis in greater detail [1.12].

All of the papers in this book cover certain basic aspects of their respective application areas, including the need for image processing in the area, hardware and software requirements, and a guide to the literature. However, the emphasis differs considerably from paper to paper, due to differences in the nature and history of the areas, as well as in the writers' personal interests and styles. The treatment of image processing and recognition techniques also differs in breadth and depth from paper to paper. To provide a unifying perspective, the following paragraphs discuss some of these techniques, and indicate their roles in each of the individual papers.

Pictorial pattern recognition can have several possible goals:
1) *Matching* pictures with one another, e.g., to detect changes, or to locate objects in three dimensions.
2) *Classifying* a picture into one of a specified set of classes, based on the values of a set of "features" measured on the picture; or using these values to describe the picture.
3) *Segmenting* a picture into significant parts, and classifying or describing the parts as above.
4) *Recognizing* a picture as being composed of specified parts in specified relationships to one another.
These goals are all applicable to many different types of pictures; but they play more prominent roles in some applications than in others.

It is often necessary to "preprocess" the given picture(s), in order to improve the reliability of subsequent matching, feature measurement, or segmentation. An important type of preprocessing is *normalization*, in which the picture is brought into a standard form, in order to make feature values independent of, or at least insensitive to, various transformations which may have affected the original picture. Grayscale normalization is discussed by HARALICK (Subsect. 2.3.1); the need for such normalization is greatest in the case of remote sensor imagery, where the illumination is uncontrolled (except in the case of radar imagery). A common method of grayscale normalization is to standardize the picture's histogram (=gray level frequency distribution); on histograms see also Subsection 5.5.1. HARALICK also discusses the removal of perspective distortion from pictures (rectification; Subsect. 2.3.2), which is an important example of geometrical normalization. Size normalization (of characters that have been segmented from a document) is treated by ULLMANN (Sect. 6.5), who also discusses smoothing of the segmented characters (Sect. 6.4); these techniques are appropriate when dealing with specific, non-noisy shapes that can have a wide range of sizes. A number of basic preprocessing techniques are also mentioned by HARLOW (Subsect. 3.3.2).

Matching, or correlation, plays a major role in the recognition of characters that have known shapes (Sect. 6.6). It is also important in stereogrammetry (the location of objects in three dimensions by comparing pictures taken from two or more viewpoints); an example discussed by McILWAIN is the spatial location of bubble tracks (Subsect. 4.3.3). Image registration and "congruencing" for matching or comparison purposes are discussed by HARALICK (Subsect. 2.3.2).

Many types of features can be used for picture classification. Simple template-like features are appropriate for classifying patterns of known shape, such as characters (Sect. 6.7). When geometrical distortions are present, however, it becomes necessary to use features that are insensitive to these distortions, e.g., topological features (Sect. 6.8). A variety of size and shape features are discussed in Subsections 5.5.2, 5.5.3, and 5.5.5, while recognition based on the occurrence of subpatterns in specific sequences ("strip classification") is treated in Section 6.9.

In cytology, radiology, and remote sensing, not only the sizes and shapes of objects (or regions) are important, but also their textures. Approaches to the measurement of texture features are discussed by HARALICK (Sect. 2.5), HARLOW (Subsect. 3.3.3), and PRESTON (Subsects. 5.5.6 and 5.5.7).

Picture segmentation is important in nearly every application of pictorial pattern recognition. In character recognition, one needs to separate the printing or writing from the background ("binarization"; Sect. 6.3), and also to segment it into individual characters (Sect. 6.5). In high-energy physics, one needs to detect tracks and vertices (Subsects. 4.3.1 and 4.3.2). Other segmentation techniques, including both thresholding and edge detection, play important roles in cytology (Subsect. 5.5.4), radiology (Subsect. 3.3.4), and remote sensing applications.

A wide variety of pattern classification techniques have been developed, including methods of classification based on given features; methods of feature selection; and methods of defining natural classes by cluster detection (or unsupervised learning). HARALICK discusses some of these ideas in Section 2.4, and they are also briefly treated by HARLOW (Subsect. 3.3.1) and PRESTON (Subsect. 5.5.9).

Many books have appeared during the past few years on pattern classification techniques. Among these, mention should be made of a recent semi-monograph, reviewing basic methods and approaches, which appeared in the Springer series *Communication and Cybernetics* [1.13]. This book can serve to provide the reader of the present volume with a general theoretical background in pattern recognition principles, most of which are broadly applicable to the field of digital picture analysis.

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2. Automatic Remote Sensor Image Processing

R. M. HARALICK

With 10 Figures

2.1 Remote Sensing

Detecting the nature of an object by external observation, without physical contact with the object, is remote sensing. The advantages of gathering data about objects remotely are that the object is usually not disturbed; objects in inaccessible areas can be examined; and a large amount of information over any spatial area can be obtained.

The earliest and most useful form of remote sensing is photography. Here, photon energy (in the visible or near-visible portion of the spectrum) which is radiating or reflected from objects is collected by a camera (the sensor) and recorded on a light sensitive film emulsion. Aerial multiband and color photography can be used to determine the number of acres of land in different uses, such as rangeland, cropland, forest, urban, swamp, marsh, water, etc. It can help identify rock and soil type, vegetation, and surface water condition [2.1, 2].

The camera, of course, is not the only kind of remote sensor. Other types of remote sensors include the multispectral scanner, the infrared scanner, the scanning radiometer, the gamma ray spectrometer, the radar scatterometer, and the radar imager. Figure 2.1 illustrates the typical scanning sensor. A rotating mirror scans the ground scene in a line by line manner with the forward velocity of the sensing platform causing the line scans to be successively displaced. The mirror directs the received energy to a detector which converts it to a video signal which is then recorded by a film recorder to make an image. Thermal infrared scanner systems can produce imagery in daytime or nighttime since their detectors are sensitive to emitted heat and not to light. The near-infrared systems are able to penetrate haze and dust making it possible to get good contrast images not achievable by aerial photography. MALILA [2.3] documented the advantages multispectral scanners have over cameras for image enhancement and discrimination. The NASA Third and Fourth Annual Earth Resources Program Reviews [2.4, 5] and the Michigan Symposia on Remote Sensing of Environment contain numerous papers on the application of multispectral or thermal scanners. See also [2.6, 7].

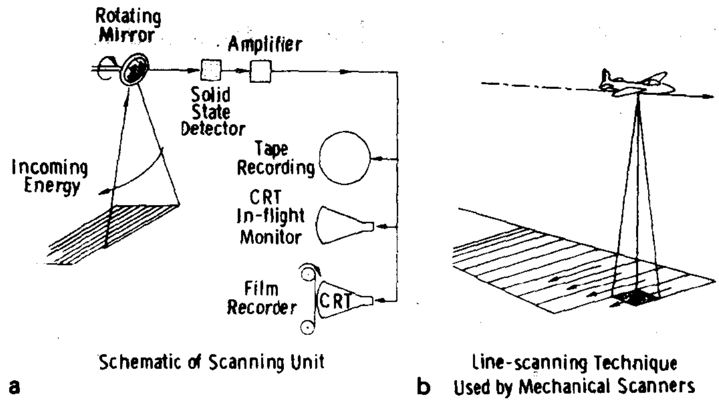

Fig. 2.1. (a) Schematic of scanning unit. (b) Line-scanning technique used by mechanical scanners.

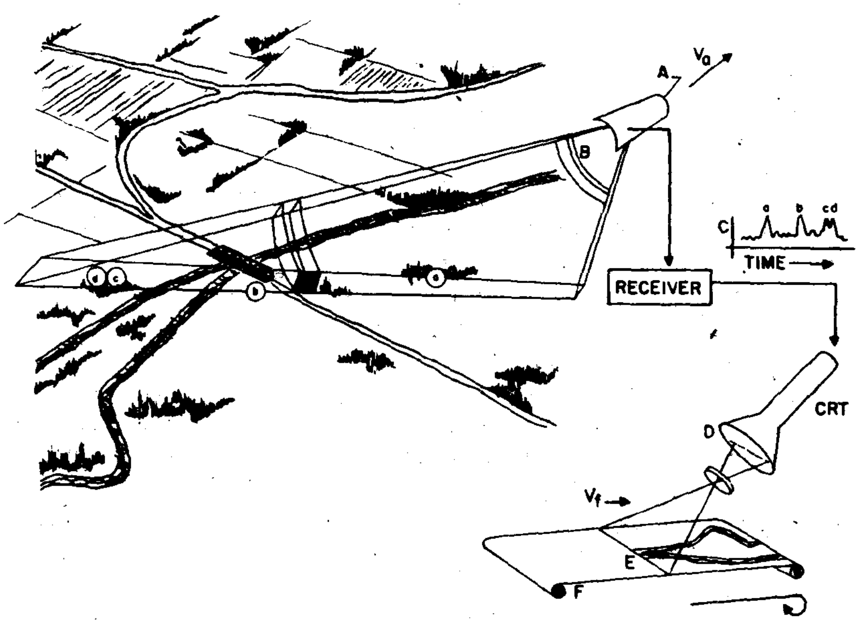

Fig. 2.2. Side-looking radar scanning

The radar imager shown in Fig. 2.2, unlike the others, is an active system. It illuminates the ground scene by transmitting its own microwave radiation and its antenna receives the reflected energy. After appropriate processing and electronic amplification the resulting video signal can be recorded by film recorder to make an image. The radar

Table 2.1. Agriculture/forestry

Application	Type of data Required	Data use
Agriculture	Inventory and distribution	Farm/forest interfaces Boundaries Topographic maps Crop type and density Crop expected yield Livestock census
	Infestation	Disease damage Insect damage Infestation patterns
	Land use	Soil texture Soil moisture and irrigation requirements Soil quality to support vegetation Farm planning
Forestry	Inventory and distribution	Forest texture Boundaries Topographic maps Tree types and count Logging yield and production Location of tree types
	Fire, disease and reclamation	Fire location and damage Pattern and discontinuity Soil moisture and texture Insect and disease damage
Conservation	Land use Grassland vigor	Maps Wildlife management

signal is influenced by ground conductivity and surface roughness. Radar images are particularly good at providing integrated landscape analysis [2.8–8a], as well as vegetation [2.9], geologic [2.10], and soil moisture [2.11] information.

Tables 2.1–5 list the variety of uses to which earth resources remote sensing has been put in the areas of agriculture, forestry, hydrology, geology, geography, and environment monitoring. MERIFIELD et al. [2.12] discussed the potential applications of spacecraft imagery.

The success of manual interpretation or automatic processing of remotely sensed imagery is constrained by the kind of physical character-