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Preface

The Importance of Color

Color plays an important role in our visual world: we are attracted more by tones of color than by shades of gray. The human visual system (HVS) can sense, analyze, and appreciate more tones of color than shades of gray at a given time and under a given set of viewing conditions. The colors and skin tones of our bodies, the colors and texture of the clothes we wear, and the colors of the natural scenery that surrounds us are all innate aspects of our lives. Who would not be thrilled to view a meadow filled with a splash of colorful flowers? Who would not be mesmerized by the extravagant colors of corals and tropical fishes in a reef? Who would not be excited with a surprise gift of a bouquet of flowers with a burst of colors?

Color permeates our world and life. We are so accustomed to color that we use related words, for example, "colorful," to describe nonvisual entities such as personalities. Indeed, a world without color would be very dull — and gray!

The Growing Popularity of Color Imaging

With the increasing popularity of computers and digital cameras as personal devices for education, research, communication, professional work, as well as entertainment, the use of images in day-to-day life is growing by leaps and bounds. Personal computers (PCs) have standard features and accessories for the acquisition of images via scanners, still cameras, and video cameras, as well as easy downloading of images from the Internet, the Web, or storage devices such as compact discs (CDs) and digital versatile (or video) discs (DVDs). The acquisition, manipulation, and printing of personal or family photos have now become an easy (and even pleasant!) task for an individual who is not necessarily at ease with computers. Needless to say, color is a significant aspect of all of the above.

From Grayscale to Color Image Processing

Digital image processing (DIP) — the manipulation of images in digital format by computers — has been an important field of research and development since the 1960s [1–12]. Much of the initial work in DIP dealt exclusively with monochromatic or grayscale images. (See the special issues of the *Proceedings of the IEEE,* July 1972 and May 1979, for historically significant papers on DIP.) In fact, the processing of images in just black and white (binary images) has been an important area with applications in facsimile transmission (fax) and document analysis.

As the knowledge and understanding of techniques for DIP developed, so did the recognition of the need to include color. With remote sensing of the Earth and its environment using satellites [13], the need also grew to consider more general representations of images than the traditional tristimulus or three-channel characterization of natural color images. Multispectral or hyperspectral imaging with tens of channels or several hundred bands of spectral sensitivity spanning a broad range of the electromagnetic spectrum well beyond the range of visible light is now common, with real-life applications including land-use mapping, analysis of forest cover and deforestation, detection of lightning strikes and forest fires, analysis of agricultural plantations and prediction of crop yield, and extreme weather or flood warning.

Nowadays, medical diagnosis depends heavily upon imaging of the human body. Most medical images, such as those obtained using X rays and ultrasound, are scalar-valued, lack inherent color, and are represented as monochromatic or grayscale images. However, (pseudo-)color is used for enhanced visualization in the registration of multimodality images. Limited colors are used to encode the velocity and direction of blood flow in Doppler imaging. Staining in pathology and cytology leads to vividly colored images of various tissues [14–17]. Even in the case of analysis of external signs and symptoms, such as skin rashes and burns, color imaging can play important roles in enhanced visualization using polarized lighting, transmission, and archival. The application of DIP techniques to images as above calls for the development of specialized techniques for the representation, characterization, and analysis of color.

Initial work on color image processing (CIP) was based on the direct (and simplistic) application of grayscale DIP techniques to the individual channels of color or multispectral images. Although some useful results could be obtained in this manner, it was soon realized that it is important to develop specialized techniques for CIP, taking into consideration the correlation and dependencies that exist between the channels [1–5, 12, 18–20]. (See the January 2005 special issue of the *IEEE Signal Processing Magazine* on color image processing.) Whereas several books are available on the science of color perception, imaging, and display [12, 21–28], very few books on DIP have significant examples, sections, or chapters on CIP [1–5, 11, 12, 20, 24], and fewer still are dedicated to CIP [18,19,29,30]. In this book, we shall mainly consider techniques that are specifically designed for CIP.

The Plan of the Book

We begin with a detailed study of the nature of color images. In addition to natural color images, we take into consideration multispectral and pseudocolor images in specialized areas such as photogrammetric and biomedical imaging. Chapter 1 provides descriptions of the HVS, color perception, color-matching functions, and systems for the representation of color images. A pertinent selection of biomedical applications is provided at the end of each chapter, including diagnostic imaging of the retina and imaging of skin lesions.

In Chapter 2, we present details regarding the acquisition, creation, and quality control of color images. Despite the simple appearance and usage of digital cameras, the chain of systems and techniques involved in the acquisition of color images is complex; regardless, the science of imaging is now a well-developed and established subject area [12,24,31]. Several operations are required to ensure faithful reproduction of the colors in the scene or object being imaged, or to assure a visually pleasing and acceptable rendition of the complex tonal characteristics in a portrait; the latter hints at the need to include personal preferences and subjective aspects, whereas the former implies rigid technical requirements and the satisfaction of quantitative measures of image characteristics. In addition to processes involving natural color images, we describe techniques related to staining in pathology and the use of fluorescent dyes in confocal microscopy for imaging of biomedical specimens. We present biomedical applications including the acquisition of images of burn wounds and endoscopy.

In Chapter 3, we study the issue of noise and artifacts in color images as well as methods to remove them. The need to consider the interrelationships that exist between the components or channels of color images is emphasized, leading to the formulation of vector filters.

In spite of the high level of sophistication (and cost) of cameras and image-acquisition systems, it is common to acquire or encounter images of poor quality. Image quality is affected by several factors, including the lighting conditions, the environment, and the nature of the scene or object being imaged, in addition to the skills and competence of the individual capturing the image. The topic of image enhancement is considered in Chapter 4, including methods for hue-preserving enhancement, contrast enhancement, sharpening, and histogram-based operations.

Segmentation for the detection of regions of interest or objects is a critical step in the analysis of images. Although a large body of literature exists on this topic, it is recognized that no single technique can directly serve a new purpose: every application or problem demands the development of a specific technique that takes into account the particular characteristics of the images and objects involved. The problem is rendered more complex by the multichannel nature of color images. In Chapter 5, we explore several methods for the detection of edges and objects in color images. Several biomedical applications are presented, including the segmentation and analysis of skin lesions and retinal vasculature.

Chapter 6 provides a few closing remarks on the subjects described in the book and also on advanced topics to be presented in a companion book to follow.

The Intended Audience and Learning Plans

The methods presented in the book are at a fairly high level of technical and mathematical sophistication. A good background in one-dimensional signal and system analysis [32–34] is required in order to follow the procedures and analyses. Familiarity with the theory of linear systems, signals, and transforms, in both continuous and discrete versions, is assumed. Furthermore, familiarity with the basics of DIP [1–9] is assumed and required.

We only briefly study a few representative imaging or image-data acquisition techniques. We study in more detail the problems present with images after they have been acquired, and concentrate on how to solve the problems. Some preparatory reading on imaging systems, equipment, and techniques [12,24,31] would be useful, but is not essential.

The book is primarily directed at engineering students in their (post-)graduate studies. Students of electrical and computer engineering with a good background in signals and systems [32–34] are expected to be well prepared for the material in the book. Students in other engineering disciplines or in computer science, physics, mathematics, or geophysics should also be able to appreciate the material in this book. A course on digital signal processing or digital filters [35] would form a useful link, but a capable student without familiarity of this topic may not face much difficulty. Additional study of a book on DIP [1–9] can assist in developing a good understanding of general image-processing methods.

Practicing engineers, researchers, computer scientists, information technologists, medical physicists, and data-processing specialists working in diverse areas such as DIP, computer vision, pattern recognition, telecommunications, seismic and geophysical applications, biomedical applications, hospital information systems, remote sensing, mapping, and geomatics may find this book useful in their quest to learn advanced techniques for the analysis of color or multichannel images.

Practical experience with real-life images is a key element in understanding and appreciating image analysis. We strongly recommend hands-on experiments with intriguing real-life images and technically challenging image-processing algorithms. This aspect can be difficult and frustrating at times, but provides professional satisfaction and educational fun!

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July 2011

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Rangaraj (Raj) Mandayam Rangayyan is a Professor with the Department of Electrical and Computer Engineering, and an Adjunct Professor of Surgery and Radiology, at the University of Calgary, Calgary, Alberta, Canada. He received the Bachelor of Engineering degree in Electronics and Communication in 1976 from the University of Mysore at the People's Education Society College of Engineering, Mandya, Karnataka, India, and the Ph.D. degree in Electrical Engineering from the Indian Institute of Science, Bangalore, Karnataka, India, in 1980. His research interests are in the areas of digital signal and image processing, biomedical signal analysis, biomedical image analysis, and computer-aided diagnosis. He has published about 140 papers in journals and 230 papers in proceedings of conferences. His research productivity was recognized with the 1997 and 2001 Research Excellence Awards of the Department of Electrical and Computer Engineering, the 1997 Research Award of the Faculty of Engineering, and by appointment as a "University Professor" in 2003, at the University of Calgary. He is the author of two textbooks: *Biomedical Signal Analysis* (IEEE/Wiley, 2002) and *Biomedical Image Analysis* (CRC, 2005); he has coauthored and coedited several other books. He was recognized by the IEEE with the award of the Third Millennium Medal in 2000, and was elected as a Fellow of the IEEE in 2001, Fellow of the Engineering Institute of Canada in 2002, Fellow of the American Institute for Medical and Biological Engineering in 2003, Fellow of SPIE in 2003, Fellow of the Society for Imaging Informatics in Medicine in 2007, Fellow of the Canadian Medical and Biological Engineering Society in 2007, and Fellow of the Canadian Academy of Engineering in 2009. He has been awarded the Killam Resident Fellowship thrice (1998, 2002, and 2007) in support of his projects on writing books.

Begoña Acha Piñero was born in Seville, Spain. She received the Bachelor of Engineering degree in Communications in 1996 and the Ph.D. degree in Communication Engineering in 2002, both from the University of Seville, Spain. She has been teaching and conducting research at the University of Seville since 1996. Her present position is Tenured Professor, Signal Processing and Communications Department, University of Seville. Her current research activities include works in the field of color image processing and its medical applications, in particular, segmentation, classification, and compression. She has also been conducting research on mammographic and retinal images. Her research interest includes segmentation and retrieval of radiological images in a virtual reality environment.

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