COLOR IMAGE PROCESSING

Methods and Applications

Edited by

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Color television! Bah, I won't believe it until I see it in black and white.

—*Samuel Goldwyn*
Movie producer

To my dear parents whose constant love and support have made my achievements possible.

R. Lukac

To the loving memory of my father.

K. N. Plataniotis

Preface

Over the last two decades, we have witnessed an explosive growth in both the diversity of techniques and the range of applications of image processing. However, the area of color image processing is still sporadically covered, despite having become commonplace with consumers choosing the convenience of color imaging over traditional gray-scale imaging. With advances in imaging sensors, digital TV, image databases, video and multimedia systems, and with the proliferation of color printers, color image displays, DVD devices, and especially digital cameras and image-enabled consumer electronics, color image processing appears to become the main focus of the image processing research community. Processing color images or, more generally, processing multichannel images, such as satellite images, color filter array images, microarray images, and color video sequences, is a nontrivial extension of the classical gray-scale processing. Indeed, the vectorial nature of multichannel images suggests a different approach — that of vector algebra and vector fields — should be utilized in approaching this research problem. Recently, there have been many color image processing and analysis solutions, and many interesting results have been reported concerning filtering, enhancement, restoration, edge detection, analysis, compression, preservation, manipulation and evaluation of color images. The surge of emerging applications, such as single-sensor imaging, color-based multimedia, digital rights management, art and biomedical applications indicate that the demand for color imaging solutions will grow considerably in the next decade.

The purpose of this book is to fill the existing literature gap and comprehensively cover the system, processing and application aspects of digital color imaging. Due to the rapid developments in specialized areas of color image processing, this book has the form of a contributed volume where well-known experts address specific research and application problems. It presents the state-of-the-art as well as the most recent trends in color image processing and applications. It serves the needs of different readers at different levels. It can be used as textbook in support of a graduate course in image processing or as stand-alone reference for graduate students, researchers and practitioners. For example, the researcher can use it as an up-to-date reference since it offers a broad survey of the relevant literature. Finally, practicing engineers may find it useful in the design and the implementation of various image and video processing tasks.

This book details recent advances in digital color imaging and multichannel image processing methods and explores emerging color image, video, multimedia and biomedical processing applications. The first few chapters focus on color fundamentals, targeting three critical areas: color management, gamut mapping and color constancy. The remaining chapters explore color image processing approaches across a broad spectrum of emerging applications ranging from vector processing of color images, segmentation, resizing and compression, halftoning, secure imaging, feature detection and extraction, image retrieval, semantic processing, face detection, eye tracking, biomedical retina image analysis, real-time processing, digital camera image processing, spectral imaging, enhancement for plasma display panels, virtual restoration of artworks, image colorization, super-resolution image reconstruction, video coding, video shot segmentation and surveillance.

Chapters 1 to 3 discuss the concepts and technology which are essential to ensure constant color appearance in different devices and/or media. This part of the book covers issues related to color management, color gamut mapping and color constancy. Given the fact that each digital imaging device exhibits unique characteristics, its calibration and characterization using a *color management system* are of paramount importance to obtain predictable and accurate results when transferring the color data from one device to another. Similarly, each media has its own achievable color gamut. This suggests that some colors can often not be reproduced to precisely match the original, thus requiring *gamut mapping* solutions to overcome the problem. Since the color recorded by the eye or a camera is a function of the reflectances in the scene and the prevailing illumination, *color constancy* algorithms are used to remove color bias due to illumination and restore the true color information of the surfaces.

Chapters 4 through 7 are intended to cover the basics and overview recent advances in traditional color image processing tasks such as filtering, segmentation, resizing and halftoning. Due to the presence of noise in many image processing systems, noise filtering or estimation of the original image information from noisy data is often used in order to improve perceptual quality of an image. Since edges convey essential information about a visual scene, edge detection allows imaging systems to better mimic the human perception of the environment. Modern *color image filtering* solutions which rely on the trichromatic theory of color are suitable for both above tasks. *Image segmentation* refers to partitioning the image into different regions that are homogeneous with respect to some image features. It is a complex process involving components relative to the analysis of color, shape, motion, and texture of objects in the visual data. Image segmentation is usually the first task in the lengthy process of deriving meaningful understanding of the visual input. *Image resizing* is often needed for the display, storage, and transmission of images. Resizing operations are usually performed in the spatial domain. However, as most images are stored in compressed formats, it is more attractive to perform resizing in a transform domain, such as the discrete cosine transform domain used in most compression engines. In this way, the computational overhead associated with the decompression and compression operations on the compressed stream can be considerably reduced. *Digital halftoning* is the method of reducing the number of gray-levels or colors in a digital image while maintaining the visual illusion that the image still has a continuous-tone representation. Halftoning is needed to render a color image on devices which cannot support many levels or colors, e.g., digital printers and low-cost displays. To improve a halftone image's natural appearance, color halftoning relies heavily on the properties of the human visual system.

Chapter 8 introduces *secure color imaging* using secret sharing concepts. Essential encryption of private images, such as scanned documents and personal digital photographs, and their distribution in multimedia networks and mobile public networks, can be ensured by employing secret sharing based image encryption technologies. The images, originally available in a binary or halftone format, can be directly decrypted by the human visual system at the expense of the reduced visual quality. Using the symmetry between encryption and decryption functions, secure imaging solutions can be used to restore both binarized and continuous-tone secret color images in their original quality.

Chapters 9 to 11 address important issues in the areas of object recognition, image matching, indexing and retrieval. Many of the above tasks rely on the use of discriminatory and robust *color feature detection* to improve color saliency and determine structural elements such as shadows, highlights and object edges/corners. Extracted features can help to group the image into distinctive parts to associate them with individual chromatic attributes and mutual spatial relationships. The utilization of both color and spatial information in *image retrieval* ensures effective access to archives and repositories of digital images. *Semantic processing* of color images can potentially increase the usability and applicability of color image databases and repositories. Application areas such as surveillance and authentication, content filtering, transcoding, and human and computer interaction can benefit directly from improvements of tools and methodologies in color image analysis.

Chapters 12 to 14 cover face and eye-related color image processing. Color cues have been proven to be extremely useful in *facial image analysis*. However, the problem with color cue is its sensitivity to illumination variations which can significantly reduce the performance of face detection and recognition algorithms. Thus, understanding the effect of illumination and quantifying its influence on facial image analysis tools has become an emerging area of research. As the pupil and the sclera are different in color from each other and from the surrounding skin, color can be seen a useful cue also in *eye detection and tracking*. Robust eye trackers usually utilize the information from both visible and invisible color spectra and are used in various human computer interaction applications such as fatigue and drowsiness detection and eye typing. Apart from biometrics and tracking applications, color image processing can be helpful in biomedical applications such as *automated identification of diabetic retinal exudates*. Diagnostic analysis of retinal photographs by an automated computerized system can detect disease in its early stage and reduce the cost of examination by an ophthalmologist.

Chapters 15 through 18 address the important issue of color image acquisition, real-time processing and displaying. *Real-time imaging systems* comprise a special class of systems which underpin important application domains including industrial, medical, and national defense. The understanding of the hardware support is often fundamental to the analysis of real-time performance of a color imaging system. However, software, programming language and implementation issues are also essential elements of a real-time imaging system as algorithms must be implemented in some programming language and hardware devices interface with the rest of the system using software components. The typical example of the real-time color imaging system is a digital camera. In the most popular camera configuration, the true color visual scene is captured using a color filter array-based single image sensor and the acquired data must be pre-processed, processed and post-processed to produce the captured color image in its desired quality and resolution. Thus, *single-sensor camera image processing* typically involves real-time interpolation solutions to complete demosaicking, enhancement and zooming tasks. Real-time performance is also of paramount importance in *spectral imaging* for various industrial, agricultural and environmental applications. Extending three color components up to hundreds or more spectral channels in different spectral bands requires dedicated sensors in particular spectral ranges and specialized image processing solutions to enhance and display the spectral image data. Most display technologies have to efficiently render the image data in the highest visual quality. For instance, *plasma display panels use image enhancement* to faithfully reproduce dark areas, reduce dynamic false contours and ensure color fidelity.

Chapters 19 to 21 deal with other applications of color image enhancement. Recent advances in electronic imaging have allowed for *virtual restoration of artworks* using digital image processing and restoration techniques. The usefulness of this particular kind of restoration consists of the possibility to use it as a guide to the actual restoration of the artwork or to produce a digitally restored version of the artwork, as it was originally. *Image and video colorization* adds the desired color to a monochrome image or movie in a fully automated manner or based on a few scribbles supplied by the user. By transferring the geometry of the given luminance image to the three dimensional space of color data, the color is inpainted, constrained both by the monochrome image geometry and the provided color samples. Apart from the above applications, *super-resolution color image reconstruction* aims to reduce the cost of optical devices and overcome the resolution limitations of image sensors by producing a high-resolution image from a sequence of low-resolution images. Since each video frame or color channel may bring unique information to the reconstruction process, the use of multiple low-resolution frames or channels provides the opportunity to generate the desired output in higher quality.

Finally, Chapters 22 through 24 discuss various issues in color video processing. *Coding of image sequences* is essential in providing bandwidth efficiency without sacrificing video quality. Reducing the bit rate needed for the representation of a video sequence enables the transmission of the stream over a communication channel or its storage in an optical medium. To obtain the desired coding performance, efficient video coding algorithms usually rely on motion estimation and geometrical models of the object in the visual scene. Since the temporal nature of video is responsible for its semantic richness, temporal video segmentation using *shot boundary detection* algorithms is often a necessary first step in many video processing tasks. The process segments the video into a sequence of scenes, which are subsequently segmented into a sequence of shots. Each shot can be represented by a key-frame. Indexing the above units allows for efficient video browsing and retrieval. Apart from traditional video and multimedia applications, processing of color image sequences constitutes the basis for the development of *automatic video systems for surveillance applications*. For instance, the use of color information assists operators to classify and understand complex scenes, detect changes and objects on the scene, focus attention on objects of interest and track objects of interest.

The bibliographic links included in the various chapters of the book provide a good basis for further exploration of the topics covered in this edited volume. The volume includes numerous examples and illustrations of color image processing results, as well as tables summarizing the results of quantitative analysis studies. Complementary material including full-color electronic versions of results reported in this volume are available online at the

http://www.dsp.utoronto.ca/ColorImaging

We would like to thank the contributors for their effort, valuable time and motivation to enhance the profession by providing material for a fairly wide audience while still offering their individual research insights and opinions. We are very grateful for their enthusiastic support, timely response, and willingness to incorporate suggestions from us, from other contributing authors, and from a number of colleagues in the field who served as reviewers. Particular thanks are due to the reviewers whose which helped to improve the quality of contributions. Finally, a word of appreciation for CRC Press for giving us the opportunity to edit a book on color image processing. In particular, we would like to thank Dr. Phillip A. Laplante for his encouragement, Nora Konopka for initiating this project, Helena Redshaw for her support and assistance at all times.

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About the Editors

Rastislav Lukac (http://www.dsp.utoronto.ca/~lukacr) received the M.S. (Ing.) and Ph.D. degrees in Telecommunications from the Technical University of Kosice, Slovak Republic in 1998 and 2001, respectively. From February 2001 to August 2002 he was an Assistant Professor with the Department of Electronics and Multimedia Communications at the Technical University of Kosice. During August 2002 to July 2003 he was a Researcher with the Slovak Image Processing Center in Dobsina, Slovak Republic. From January 2003 to March 2003 he was a Postdoctoral Fellow with the Artificial Intelligence and Information Analysis Laboratory, Aristotle University of Thessaloniki, Greece. Since May 2003 he has been a Post-doctoral Fellow with the Edward S. Rogers Sr. Department of Electrical and Computer Engineering, University of Toronto in Toronto, Canada. He is a contributor to four books and he has published over 200 papers in the areas of digital camera image processing, color image and video processing, multimedia security, and microarray image processing.

Dr. Lukac is a Member of the IEEE, EURASIP, and IEEE Circuits and Systems, IEEE Consumer Electronics, and IEEE Signal Processing societies. He is a Guest Co-Editor of the Real-Time Imaging, Special Issue on Multi-Dimensional Image Processing, and of the Computer Vision and Image Understanding, Special Issue on Color Image Processing for Computer Vision and Image Understanding. He is an Associate Editor for the Journal of Real-Time Image Processing. He serves as a Technical Reviewer for various scientific journals and he participates as a Member of numerous international conference committees. In 2003, he was the recipient of the NATO/NSERC Science Award.

Konstantinos N. Plataniotis (http://www.dsp.utoronto.ca/∼kostas) received the B. Engineering degree in Computer Engineering from the Department of Computer Engineering and Informatics, University of Patras, Patras, Greece in 1988 and the M.S and Ph.D degrees in Electrical Engineering from the Florida Institute of Technology (Florida Tech), Melbourne, Florida in 1992 and 1994 respectively. From August 1997 to June 1999 he was an Assistant Professor with the School of Computer Science at Ryerson University. He is currently an Associate Professor at the Edward S. Rogers Sr. Department of Electrical & Computer Engineering where he researches and teaches image processing, adaptive systems, and multimedia signal processing. He co-authored, with A.N. Venetsanopoulos, a book on ”Color Image Processing & Applications”, Springer Verlag, May 2000, ISBN 3-540-66953-1, he is a contributor to seven books, and he has published more than 300 papers in refereed journals and conference proceedings in the areas of multimedia signal processing, image processing, adaptive systems, communications systems and stochastic estimation.

Dr. Plataniotis is a Senior Member of IEEE, an Associate Editor for the IEEE Transactions on Neural Networks, a past member of the IEEE Technical Committee on Neural Networks for Signal Processing. He was the Technical Co-Chair of the Canadian Conference on Electrical and Computer Engineering (CCECE) 2001, and CCECE 2004. He is the Technical Program Chair of the 2006 IEEE International Conference in Multimedia and Expo (ICME 2006), the Vice-Chair for 2006 IEEE Intelligent Transportation Systems Conference (ITSC 2006), and the Image Processing Area Editor for the IEEE Signal Processing Society e-letter. He is the 2005 IEEE Canada “Outstanding Engineering Educator” Award recipient and the co-recipient of the 2006 IEEE Transactions on Neural Networks Outstanding Paper Award.

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