PRACTICAL IMAGE AND VIDEO PROCESSING USING MATLAB®

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About the Cover (by Roger Dalal)
The elegant Nautilus, with its progressive chambers and near-perfect logarithmic spiral, demonstrates the beauty of mathematics and the power of digital image processing. Created exclusively for *Practical Image and Video Processing Using MATLAB®*, this composition features multiple layers and processing techniques. The primary image is doubly sharpened with an 8 pixel radius, and enhanced with posterizing and edge detection algorithms. The outer, secondary image is indexed to 20 colors, pixelized at two percent resolution of the center image, and partially hidden by a fading, offset radial mask.

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To my Son Nicholas, whose Precious Existence has Provided the Greatest Motivation to Pursue this Project.

And in Loving Memory of my Father, Ogê Aby Marques.

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FOREWORD

In packing for an office move earlier this year, I was struck by how many of my books (in many cases books sent to me free by their publishers for evaluation and potential use) were knockoffs: books that repackaged material that had been thoroughly consolidated in good textbooks years or even decades ago. Oge Marques' textbook is not a knockoff, even though much its subject matter has been around for years. It is a thoughtful and original compilation of material that is highly relevant today for students of imaging science, imaging technology, image understanding, and, foremost, image processing.

Imaging is my principal field of expertise. My interest in this book is great because imaging and image processing have grown together in recent years. Some forms of imaging—computational imaging is the buzzword that comes first to mind—presume that there will be (must be, in fact) postdetection processing of the raw information collected by the sensor system. Indeed, the sensor may output something that makes little or no sense to the observer in the absence of critical postprocessing operations.

Ultimately, in commercial mass-produced systems, image processing is implemented by specialized hardware. In the research and development stages of an imaging system, however, the processing is almost certain to be implemented using MATLAB®. Marques' book addresses this fact by linking directly to MATLAB® the many processing operations that are described.

There are of course numerous texts that describe digital image processing operations and algorithms. None, however, emphasizes as this one does the human vision system and the interaction and intercomparison between that system and machine vision systems.

The book contains a wealth of practical material and an invaluable up-to-date list of references, including journals, periodicals, and web sites. I would hope that the

book sees subsequent editions, with correspondingly updated lists. Also invaluable to the teacher is the inclusion, now characteristic of many contemporary textbooks, of concise chapter summaries that address the question "What have we learned?" Tutorials punctuate the text, taking the students through important material in an active-learning process.

I write this foreword not just because I think this book addresses its intended image processing audience well but also because I see it influencing the thinking of my own students, students interested in imaging systems from a physics and technological standpoint but who must understand the relationship between imaging systems and image processing systems.

WILLIAM T. RHODES

William T. Rhodes is Emeritus Professor of Electrical & Computer Engineering at Georgia Institute of Technology. In 2005 he joined the Electrical Engineering faculty at Florida Atlantic University and became Associate Director of that university's Imaging Technology Center. A Fellow of the Optical Society of America and of the SPIE, he is editor-in-chief of the Springer Series in Optical Sciences and editor-in-chief of the online journal *SPIE Reviews*.

PREFACE

The prospect of using computers to emulate some of the attributes of the human visual system has attracted the interest of scientists, engineers, and mathematicians for more than 30 years, making the field of image processing one of the fastest-growing branches of applied computer science research. During the past 15 years, the fields of image and video processing have experienced tremendous growth and become more popular and accessible. This growth has been driven by several factors: widely available and relatively inexpensive hardware; a variety of software tools for image and video editing, manipulation, and processing; popularization of the Web and its strong emphasis on visual information, a true revolution in photography that has rendered film-based cameras all but obsolete; advances in the movie industry; and groundbreaking changes on the way we watch, record, and share TV programs and video clips.

APPROACH

This book provides a practical introduction to the most important topics in image and video processing, using MATLAB® (and its Image Processing Toolbox) as a tool to demonstrate relevant techniques and algorithms. The word *Practical* in its title is not meant to suggest a coverage of all the latest consumer electronics products in these fields; this knowledge would be superficial at best and would be obsolete shortly after (or even before!) the publication of the book. The word *Practical* should rather be interpreted in the sense of "enabling the reader/student to develop practical projects, that is, working prototypes, using the knowledge gained from the book." It also has other implications, such as the adoption of a "just enough math" philosophy,

which favors the computational, algorithmic, and conceptual aspects of the techniques described along the book, over excessive mathematical formalism.

As a result, the book should appeal not only to its original target audience when used as a textbook (namely, upper-level undergraduate and early graduate students in Computer Science, Computer Engineering, Electrical Engineering, and related courses) but also to researchers and practitioners who have access to MATLAB®, solid computing/programming skills, and want to teach themselves the fundamentals of image and video processing.

KEY FEATURES

- This is the first book to combine image processing, video processing, and a practical, MATLAB®-oriented approach to experimenting with image and video algorithms and techniques.
- Complete, up-to-date, technically accurate, and practical coverage of essential topics in image and video processing techniques.
- 37 MATLAB® tutorials, which can be used either as step-by-step guides to exploring image and video processing techniques using MATLAB® on your own or as lab assignments by instructors adopting the textbook.
- More than 330 figures and 30 tables illustrating and summarizing the main techniques and concepts described in the text.
- This book adopts a "just enough math" philosophy. Many students are intimidated by image and video processing books with heavy emphasis on the mathematical aspects of the techniques. This book addresses this issue by offering the minimal mathematical treatment necessary to fully understand a technique without sacrificing the integrity of its explanation.
- The book emphasizes and encourages practical experimentation. After presenting a topic, it invites the readers to play on their own, reinforcing and expanding what they have just learned and venturing into new avenues along the same theme.
- The book has been designed to answer the most basic questions a student/reader is likely to have when first presented with a topic. It builds on my experience teaching image and video processing courses for 20 years, and the insights acquired along the way.
- The book includes many extra features to reinforce the understanding of its topics and allow the reader to learn more about them, such as exercises and programming projects, useful Web sites, and an extensive list of bibliographical references at the end of the chapters.

A TOUR OF THE BOOK

This book has been organized into two parts: *Image Processing* and *Video Processing*.

Part I (Image Processing) starts with an introduction and overview of the field (Chapter 1) that should motivate students to devote time and effort to the material in the remaining chapters. Chapter 2 introduces the fundamental concepts, notation, and terminology associated with image representation and basic image processing operations. Chapters 3 and 4 are devoted to MATLAB® and its Image Processing Toolbox, respectively, and establish the beginning of a series of chapters with hands-on activities, presented in the form of step-by-step tutorials at the end of each chapter from this point onward (except Chapter 5). Chapter 5 discusses the factors involved in image acquisition and digitization. Chapter 6 presents arithmetic and logic operations and introduces region of interest (ROI) processing. Chapter 7 covers geometric operations, such as resizing, rotation, cropping, and warping. Chapters 8–10 are devoted to point-based (Chapter 8), histogram-based (Chapter 9), and neighborhood-based (Chapter 10) image enhancement techniques. Chapter 11 extends the reach of image processing operations to the frequency domain and presents the Fourier transform and relevant frequency-domain image filtering techniques. Solutions to the problem of image restoration—particularly in cases of noise and blurring—are discussed in Chapter 12. Chapter 13 presents a detailed coverage of mathematical morphology and its use in image processing. Chapter 14 is devoted to edge detection techniques. Chapter 15 covers image segmentation. Chapter 16 transitions from grayscale to color images and presents representative color image processing techniques and algorithms. Image compression and coding, including the most recent and relevant standards, are the subject of Chapter 17. Chapter 18 looks at the problem of feature extraction and representation and leads naturally to Chapter 19 where the resulting feature vectors could be used for classification and recognition purposes.

Part II (Video Processing) starts by presenting the main concepts and terminology associated with analog video signals and systems and digital video formats and standards (Chapter 20). It then proceeds to describe the technically involved problem of standards conversion (Chapter 21). Chapter 22 discusses motion estimation and compensation techniques, shows how video sequences can be filtered, and concludes with an example of a simple solution to the problem of object detection and tracking in video sequences using MATLAB®.

The book contains two appendices. Appendix A presents selected aspects of the human visual system that bear implications in the design of image and video processing systems. Appendix B provides a tutorial on how to develop graphical user interfaces (GUIs) in MATLAB®.

NOTES TO INSTRUCTORS

This book can be used for upper-level undergraduate or introductory graduate courses in image and video processing, for one or two semesters. Most of the material included in this book has been extensively tested in many such courses during the past 20 years. The following is a summary of recommendations for instructors adopting this textbook.

Part I is organized around a typical machine vision system, from image acquisition to pattern classification. All chapters (except Chapters 16 and 17) in Part I follow a natural logic sequence, which covers all the steps involved in acquiring images, preprocessing them to remove imperfections or improve their properties, segmenting them into objects of interest, extracting objects' features, and classifying the objects into categories. The goal of Chapter 1 is to provide breadth, perspective, early examples of what can be achieved with image processing algorithms, and a systemic view of what constitutes a machine vision system. Some instructors may want to combine this information with the material from Chapter 2 as they introduce the topic early in their courses.

The material from Chapters 3 and 4 has been carefully selected to make the book self-contained, providing students all the MATLAB® and Image Processing Toolbox information they might need for the corresponding tutorials. Readers will likely keep these two chapters for future reference should they ever require MATLAB®-related help later in the course. Instructors with limited lecture time may choose to cover both chapters briefly, assign the corresponding tutorials, and monitor students' progress as they work on the tutorials and answer the associated questions.

Chapter 5 briefly introduces the topic of image sensing and acquisition. Its main goal is to equip the reader with information on the steps needed to convert a three-dimensional (3D) real-world scene into a two-dimensional (2D) digitized version of it. Instructors teaching courses with a strong emphasis on image capture and acquisition hardware may want to supplement this material with detailed references, for example, on sensors that operate outside the visible spectrum, stereo-mounted cameras, camera calibration, and many other topics.

Chapters 6–10 are straightforward and cover essential topics in any image processing class. They also provide room for many interesting discussions, lab assignments, and small projects.

Chapter 11 may be a bit challenging to some students, due to the mathematical formalism associated with the Fourier transform. Instructors may find the interactive MATLAB® frequency-domain demo (`fddemo`) introduced in that chapter a valuable tool to develop students' confidence on their understanding of the basic concepts of frequency-domain filtering techniques. Chapter 12 builds on the knowledge from Chapters 10 and 11, with focus on noise reduction and deblurring techniques. Some instructors may prefer to tone down the discussion of noise models (Sections 12.1 and 12.2) and present the techniques described in Sections 12.3–12.5 earlier on as applications of spatial-domain and frequency-domain filtering techniques.

Chapter 13 is self-contained, which gives instructors the flexibility to adjust their level of coverage—from skipping it altogether, to covering it in detail—without major impact on the other topics in their courses.

Chapters 14 and 15 provide introductory coverage of two essential topics in any image processing course. Instructors who want to present some of these contents earlier in the course or in a different sequence should be able to easily extract the associated sections and move them to a different point in time.

Chapter 16 comprises information on color image processing and is somehow related to earlier chapters (particularly, those on enhancement, segmentation, and edge

extraction). We have made a conscious decision of keeping color in a separate chapter rather than spreading color image processing throughout the text. We believe that by the time readers reach Chapter 16, they will be able to easily navigate through its contents focusing on the differences between what they learned earlier for grayscale images and later for their color equivalent. Instructors who do not agree with this decision can easily bring sections of Chapter 16 to an earlier point in their courses.

Chapter 17 deals with image compression and coding, very extensive and technically complex topics upon which entire books have been written. Since the focus of the book is on building *practical* image processing and machine vision solutions using MATLAB®, we decided to approach the topic of image coding and compression from a broad perspective (standards in use today, categories of compression techniques and their chief characteristics, etc.) instead of attempting to embed a deeper discussion of these topics that could be potentially distracting and would most likely add little value. From a pragmatic viewpoint, since the reader's goal is to process images using MATLAB® and its rich capabilities for reading and writing images from/to a wide variety of formats (most of which use some type of compression), we focused on how to use these capabilities in a meaningful way. Instructors may want to proceed in different ways, depending on their goals, ranging from expanding the material in Chapter 17 with additional references (if image coding and compression is an important part of their course syllabus) to skipping the chapter altogether (if the course's main goal is to build a machine vision solution to a practical problem, which probably would not require that type of knowledge).

Chapters 18 and 19 are tightly interrelated. They provide the information needed to design and implement two of the most critical stages of image processing and machine vision solutions: feature extraction and pattern classification. Chapter 18 offers a wide array of choices for feature extraction and representation techniques, depending on the type of image and the specific needs of the solution being designed. Instructors may appreciate the fact that Chapter 19 provides all the basic concepts that students may need from the associated fields of pattern recognition, data mining, and information retrieval, without requiring additional references. This is particularly important if the course does not enforce prerequisites in any of these areas. The tutorial at the end of Chapter 19 was created to put the selection, design, and fine-tuning of the algorithms presented in Chapters 18 and 19 under perspective. It is my hope that at this point in the book, students will not only be fluent in MATLAB® and image processing but will also have acquired the ability to look back and reflect critically on what works, what does not, and why.

Part II is organized in three chapters, which can be used in the later part of a one- or two-semester course that combines image and video processing or at the early stages of course devoted exclusively to video processing. In the latter case, the instructor may want to supplement the material in Part II with additional references (e.g., scholarly papers in video processing and related topics in the case of graduate-level courses).

Chapter 20 covers a very broad range of topics, from basic analog video concepts to digital video standards and codecs. It offers room for expansion in multiple directions, from a deeper study of TV broadcasting systems to a more detailed analysis of contemporary video compression schemes and standards. Chapter 21 covers

the topic of standards conversion and discusses the most popular techniques used to accomplish it. Chapter 22 expands the discussion to include motion estimation and compensation, as well as (interframe and intraframe) video filtering techniques. It concludes with a practical project implemented in MATLAB® by one of my former students: an object detection and tracking system in video sequences with fixed camera and moving, complex, background. The goal of including this case study is to conclude the discussion of Part II (and the book) reminding the reader that at this point they should be knowledgeable enough to attempt similar projects (which instructors may assign as end-of-course projects).

The material in Appendix A is very relevant to image and video processing systems because it explains the relationship between properties of the human visual system and their impact on design decisions involved in building such systems. Some instructors may choose to present (part of) it earlier in their courses.

Appendix B is a practical guide to the development of GUIs for MATLAB® applications. It should empower students to develop visually attractive, interactive, and functional interfaces to their MATLAB® projects.

A note about MATLAB® and the tutorials at the end of chapters. Having used MATLAB® (and its Image Processing Toolbox) for more than a decade, I wholeheartedly agree with Rudra Pratap [Pra02] who wrote, "MATLAB®'s ease of use is its main feature." MATLAB® has a shallow learning curve, which allows the user to engage in an interactive learning style that accommodates the right degree of challenge needed to raise the user's skills by a certain amount, and so on, in a staircase-like progression. The MATLAB® tutorials included in this book have been conceived under this philosophy.

Web site

The book's companion web site (http://www.ogemarques.com) contains many supplementary materials for students and instructors: MATLAB® code for all tutorials in the book, MATLAB® code for selected figures, test images and video sequences, supplementary problems, tutorials, and projects (that could not make it to the printed version), and an ever-growing and frequently maintained list of useful web sites—including (links to) image processing conferences, software, hardware, research groups, test image databases, and much more.

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they pointed out and improve the contents of the book according to their suggestions. If any error remains, it is entirely my responsibility, not theirs. If you should find any errors, please e-mail me at omarques@ieee.org, and I will correct them in future printings of this book.

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Oge Marques