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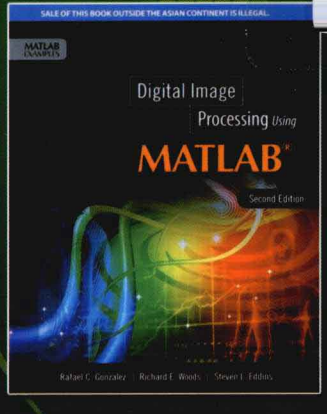
数字图像处理

(MATLAB版)(第二版)

Digital Image Processing Using MATLAB

Second Edition



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内容简介

本书是图像处理基础理论论述与以MATLAB为主要工具的软件实践方法相结合的第一本书。它集成了冈萨雷斯和伍兹所著的《数字图像处理（第三版）》一书中的重要内容和MathWorks公司的图像处理工具箱。本书的特色在于重点强调了怎样通过开发新代码来增强这些软件工具。本书在介绍MATLAB编程基础知识之后，讲述了图像处理的主要内容，具体包括灰度变换、线性和非线性空间滤波、频域滤波、图像复原与重建、几何变换和图像配准、彩色图像处理、小波、图像压缩、形态学图像处理、图像分割、区域和边界表示与描述等。

本书可供从事信号与信息处理、计算机科学与技术、通信工程、地球物理等专业的大专院校师生学习参考。

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Preface

This edition of *Digital Image Processing Using MATLAB* is a major revision of the book. As in the previous edition, the focus of the book is based on the fact that solutions to problems in the field of digital image processing generally require extensive experimental work involving software simulation and testing with large sets of sample images. Although algorithm development typically is based on theoretical underpinnings, the actual implementation of these algorithms almost always requires parameter estimation and, frequently, algorithm revision and comparison of candidate solutions. Thus, selection of a flexible, comprehensive, and well-documented software development environment is a key factor that has important implications in the cost, development time, and portability of image processing solutions.

Despite its importance, surprisingly little has been written on this aspect of the field in the form of textbook material dealing with both theoretical principles and software implementation of digital image processing concepts. The first edition of this book was written in 2004 to meet just this need. This new edition of the book continues the same focus. Its main objective is to provide a foundation for implementing image processing algorithms using modern software tools. A complementary objective is that the book be self-contained and easily readable by individuals with a basic background in digital image processing, mathematical analysis, and computer programming, all at a level typical of that found in a junior/senior curriculum in a technical discipline. Rudimentary knowledge of MATLAB also is desirable.

To achieve these objectives, we felt that two key ingredients were needed. The first was to select image processing material that is representative of material covered in a formal course of instruction in this field. The second was to select software tools that are well supported and documented, and which have a wide range of applications in the "real" world.

To meet the first objective, most of the theoretical concepts in the following chapters were selected from *Digital Image Processing* by Gonzalez and Woods, which has been the choice introductory textbook used by educators all over the world for over three decades. The software tools selected are from the MATLAB® Image Processing Toolbox™, which similarly occupies a position of eminence in both education and industrial applications. A basic strategy followed in the preparation of the current edition was to continue providing a seamless integration of well-established theoretical concepts and their implementation using state-of-the-art software tools.

The book is organized along the same lines as *Digital Image Processing*. In this way, the reader has easy access to a more detailed treatment of all the image processing concepts discussed here, as well as an up-to-date set of references for further reading. Following this approach made it possible to present theoretical material in a succinct manner and thus we were able to maintain a focus on the software implementation aspects of image processing problem solutions. Because it works in the MATLAB computing environment, the Image Processing Toolbox offers some significant advantages, not only in the breadth of its computational

tools, but also because it is supported under most operating systems in use today. A unique feature of this book is its emphasis on showing how to develop new code to enhance existing MATLAB and toolbox functionality. This is an important feature in an area such as image processing, which, as noted earlier, is characterized by the need for extensive algorithm development and experimental work.

After an introduction to the fundamentals of MATLAB functions and programming, the book proceeds to address the mainstream areas of image processing. The major areas covered include intensity transformations, fuzzy image processing, linear and nonlinear spatial filtering, the frequency domain filtering, image restoration and reconstruction, geometric transformations and image registration, color image processing, wavelets, image data compression, morphological image processing, image segmentation, region and boundary representation and description, and object recognition. This material is complemented by numerous illustrations of how to solve image processing problems using MATLAB and toolbox functions. In cases where a function did not exist, a new function was written and documented as part of the instructional focus of the book. Over 120 new functions are included in the following chapters. These functions increase the scope of the Image Processing Toolbox by approximately 40% and also serve the important purpose of further illustrating how to implement new image processing software solutions.

The material is presented in textbook format, not as a software manual. Although the book is self-contained, we have established a companion web site (see Section 1.5) designed to provide support in a number of areas. For students following a formal course of study or individuals embarked on a program of self study, the site contains tutorials and reviews on background material, as well as projects and image databases, including all images in the book. For instructors, the site contains classroom presentation materials that include PowerPoint slides of all the images and graphics used in the book. Individuals already familiar with image processing and toolbox fundamentals will find the site a useful place for up-to-date references, new implementation techniques, and a host of other support material not easily found elsewhere. All purchasers of new books are eligible to download executable files of all the new functions developed in the text at no cost.①

As is true of most writing efforts of this nature, progress continues after work on the manuscript stops. For this reason, we devoted significant effort to the selection of material that we believe is fundamental, and whose value is likely to remain applicable in a rapidly evolving body of knowledge. We trust that readers of the book will benefit from this effort and thus find the material timely and useful in their work.

RAFAEL C. GONZALEZ
RICHARD E. WOODS
STEVEN L. EDDINS

① 采用本书作为教材的教师，可获得作者提供的相关英文教辅资源，详见书末所附“教学支持说明”。——编者注

Acknowledgements

We are indebted to a number of individuals in academic circles as well as in industry and government who have contributed to the preparation of the book. Their contributions have been important in so many different ways that we find it difficult to acknowledge them in any other way but alphabetically. We wish to extend our appreciation to Mongi A. Abidi, Peter J. Acklam, Serge Beucher, Ernesto Bribiesca, Michael W. Davidson, Courtney Esposito, Naomi Fernandes, Susan L. Forsburg, Thomas R. Gest, Chris Griffin, Daniel A. Hammer, Roger Heady, Brian Johnson, Mike Karr, Lisa Kempler, Roy Lurie, Jeff Mather, Eugene McGoldrick, Ashley Mohamed, Joseph E. Pascente, David R. Pickens, Edgardo Felipe Riveron, Michael Robinson, Brett Shoelson, Loren Shure, Inpakala Simon, Jack Sklanski, Sally Stowe, Craig Watson, Greg Wolodkin, and Mara Yale. We also wish to acknowledge the organizations cited in the captions of many of the figures in the book for their permission to use that material.

R.C.G
R.E.W
S.L.E

The Book Web Site

Digital Image Processing Using MATLAB is a self-contained book. However, the companion web site at

www.ImageProcessingPlace.com

offers additional support in a number of important areas.

For the Student or Independent Reader the site contains

- Reviews in areas such as MATLAB, probability, statistics, vectors, and matrices.
- Sample computer projects.
- A Tutorials section containing dozens of tutorials on most of the topics discussed in the book.
- A database containing all the images in the book.

For the Instructor the site contains

- Classroom presentation materials in PowerPoint format.
- Numerous links to other educational resources.

For the Practitioner the site contains additional specialized topics such as

- Links to commercial sites.
- Selected new references.
- Links to commercial image databases.

The web site is an ideal tool for keeping the book current between editions by including new topics, digital images, and other relevant material that has appeared after the book was published. Although considerable care was taken in the production of the book, the web site is also a convenient repository for any errors that may be discovered between printings.

About the Authors

Rafael C. Gonzalez

R. C. Gonzalez received the B.S.E.E. degree from the University of Miami in 1965 and the M.E. and Ph.D. degrees in electrical engineering from the University of Florida, Gainesville, in 1967 and 1970, respectively. He joined the Electrical Engineering and Computer Science Department at the University of Tennessee, Knoxville (UTK) in 1970, where he became Associate Professor in 1973, Professor in 1978, and Distinguished Service Professor in 1984. He served as Chairman of the department from 1994 through 1997. He is currently a Professor Emeritus of Electrical and Computer Science at UTK.

He is the founder of the Image & Pattern Analysis Laboratory and the Robotics & Computer Vision Laboratory at the University of Tennessee. He also founded Perceptics Corporation in 1982 and was its president until 1992. The last three years of this period were spent under a full-time employment contract with Westinghouse Corporation, who acquired the company in 1989. Under his direction, Perceptics became highly successful in image processing, computer vision, and laser disk storage technologies. In its initial ten years, Perceptics introduced a series of innovative products, including: The world's first commercially-available computer vision system for automatically reading the license plate on moving vehicles; a series of large-scale image processing and archiving systems used by the U.S. Navy at six different manufacturing sites throughout the country to inspect the rocket motors of missiles in the Trident II Submarine Program; the market leading family of imaging boards for advanced Macintosh computers; and a line of trillion-byte laser disk products.

He is a frequent consultant to industry and government in the areas of pattern recognition, image processing, and machine learning. His academic honors for work in these fields include the 1977 UTK College of Engineering Faculty Achievement Award; the 1978 UTK Chancellor's Research Scholar Award; the 1980 Magnavox Engineering Professor Award; and the 1980 M. E. Brooks Distinguished Professor Award. In 1981 he became an IBM Professor at the University of Tennessee and in 1984 he was named a Distinguished Service Professor there. He was awarded a Distinguished Alumnus Award by the University of Miami in 1985, the Phi Kappa Phi Scholar Award in 1986, and the University of Tennessee's Nathan W. Dougherty Award for Excellence in Engineering in 1992. Honors for industrial accomplishment include the 1987 IEEE Outstanding Engineer Award for Commercial Development in Tennessee; the 1988 Albert Rose National Award for Excellence in Commercial Image Processing; the 1989 B. Otto Wheeley Award for Excellence in Technology Transfer; the 1989 Coopers and Lybrand Entrepreneur of the Year Award; the 1992 IEEE Region 3 Outstanding Engineer Award; and the 1993 Automated Imaging Association National Award for Technology Development.

Dr. Gonzalez is author or coauthor of over 100 technical articles, two edited books, and five textbooks in the fields of pattern recognition, image processing, and robotics. His books are used in over 1000 universities and research institutions throughout the world. He is listed in the prestigious Marquis *Who's Who in America*, Marquis *Who's Who in Engineering*, Marquis *Who's Who in the World*, and in 10

other national and international biographical citations. He is the co-holder of two U.S. Patents, and has been an associate editor of the *IEEE Transactions on Systems, Man and Cybernetics*, and the *International Journal of Computer and Information Sciences*. He is a member of numerous professional and honorary societies, including Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, and Sigma Xi. He is a Fellow of the IEEE.

Richard E. Woods

Richard E. Woods earned his B.S., M.S., and Ph.D. degrees in Electrical Engineering from the University of Tennessee, Knoxville. His professional experiences range from entrepreneurial to the more traditional academic, consulting, governmental, and industrial pursuits. Most recently, he founded MedData Interactive, a high technology company specializing in the development of handheld computer systems for medical applications. He was also a founder and Vice President of Perceptics Corporation, where he was responsible for the development of many of the company's quantitative image analysis and autonomous decision making products.

Prior to Perceptics and MedData, Dr. Woods was an Assistant Professor of Electrical Engineering and Computer Science at the University of Tennessee and prior to that, a computer applications engineer at Union Carbide Corporation. As a consultant, he has been involved in the development of a number of special-purpose digital processors for a variety of space and military agencies, including NASA, the Ballistic Missile Systems Command, and the Oak Ridge National Laboratory.

Dr. Woods has published numerous articles related to digital signal processing and is coauthor of *Digital Image Processing*, the leading text in the field. He is a member of several professional societies, including Tau Beta Pi, Phi Kappa Phi, and the IEEE. In 1986, he was recognized as a Distinguished Engineering Alumnus of the University of Tennessee.

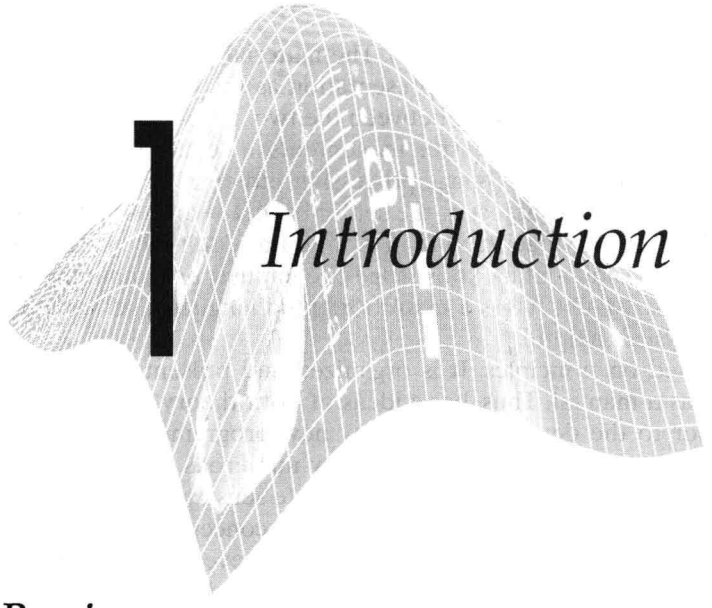
Steven L. Eddins

Steven L. Eddins is development manager of the image processing group at The MathWorks, Inc. He led the development of several versions of the company's Image Processing Toolbox. His professional interests include building software tools that are based on the latest research in image processing algorithms, and that have a broad range of scientific and engineering applications.

Prior to joining The MathWorks, Inc. in 1993, Dr. Eddins was on the faculty of the Electrical Engineering and Computer Science Department at the University of Illinois, Chicago. There he taught graduate and senior-level classes in digital image processing, computer vision, pattern recognition, and filter design, and he performed research in the area of image compression.

Dr. Eddins holds a B.E.E. (1986) and a Ph.D. (1990), both in electrical engineering from the Georgia Institute of Technology. He is a senior member of the IEEE.

Contents



1 Introduction

Preview

Digital image processing is an area characterized by the need for extensive experimental work to establish the viability of proposed solutions to a given problem. In this chapter, we outline how a theoretical foundation and state-of-the-art software can be integrated into a prototyping environment whose objective is to provide a set of well-supported tools for the solution of a broad class of problems in digital image processing.

数字图像处理的特点在于需要大量的实验工作去确立给定问题的求解方法。本章将概括地介绍把数字图像处理中的基础理论和现代软件集成为一个原型环境的方法，其目的是为求解图像处理中的各类问题提供有着良好支持的工具集。

1.1 Background
背景知识[①]

An important characteristic underlying the design of image processing systems is the significant level of testing and experimentation that normally is required before arriving at an acceptable solution. This characteristic implies that the ability to formulate approaches and quickly prototype candidate solutions generally plays a major role in reducing the cost and time required to arrive at a viable system implementation.

Little has been written in the way of instructional material to bridge the gap between theory and application in a well-supported software environment for image processing. The main objective of this book is to integrate under one cover a broad base of theoretical concepts with the knowledge required to implement those concepts using state-of-the-art image processing software tools. The theoretical underpinnings of the material in the following chapters are based on the leading textbook in the field: *Digital Image Processing*, by Gonzalez and Woods.[②] The software code and supporting tools are based on the leading software in the field: *MATLAB*® and the *Image Processing Toolbox*™

① 本书中文内容由中文版译者北京交通大学教授阮秋琦提供。——编者注

② R. C. Gonzalca and R. E. Woods, *Digital Image Processing*, 3rd cd., Prcntice Hall, Upper Saddle River, NJ, 2008.

from The MathWorks, Inc. (see Section 1.3). The material in the book shares the same design, notation, and style of presentation as the Gonzalez-Woods text, thus simplifying cross-referencing between the two.

The book is self-contained. To master its contents, a reader should have introductory preparation in digital image processing, either by having taken a formal course of study on the subject at the senior or first-year graduate level, or by acquiring the necessary background in a program of self-study. Familiarity with MATLAB and rudimentary knowledge of computer programming are assumed also. Because MATLAB is a matrix-oriented language, basic knowledge of matrix analysis is helpful.①

The book is based on principles. It is organized and presented in a textbook format, not as a manual. Thus, basic ideas of both theory and software are explained prior to the development of any new programming concepts. The material is illustrated and clarified further by numerous examples ranging from medicine and industrial inspection to remote sensing and astronomy. This approach allows orderly progression from simple concepts to sophisticated implementation of image processing algorithms. However, readers already familiar with MATLAB, the Image Processing Toolbox, and image processing fundamentals can proceed directly to specific applications of interest, in which case the functions in the book can be used as an extension of the family of toolbox functions. All new functions developed in the book are fully documented, and the code for each is included either in a chapter or in Appendix C.

We use the term *custom function* to denote a function developed in the book, as opposed to a "standard" MATLAB or Image Processing Toolbox function.

Over 120 *custom functions* are developed in the chapters that follow. These functions extend by nearly 45% the set of about 270 functions in the Image Processing Toolbox. In addition to addressing specific applications, the new functions are good examples of how to combine existing MATLAB and toolbox functions with new code to develop prototype solutions to a broad spectrum of problems in digital image processing. The toolbox functions, as well as the functions developed in the book, run under most operating systems. Consult the book web site (see Section 1.5) for a complete list.

1.2 What Is Digital Image Processing? 什么是数字图像处理?

An image may be defined as a two-dimensional function, $f(x, y)$, where x and y are *spatial coordinates*, and the amplitude of f at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point. When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a *digital image*. The field of digital image processing refers to processing digital images by means of a digital computer. Note that a digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are referred to as *picture elements*, *image elements*, *pels*, and *pixels*. *Pixel* is the term used most widely to denote the elements of a digital image. We consider these definitions formally in Section 1.7.5.

Vision is the most advanced of our senses, so it is not surprising that images play the single most important role in human perception. However, un-

① 本书自成系统。为了掌握本书的内容，读者应该有图像处理方面引导性的准备，学习过本科高年级或研究生一年级的正规课程，或者具有自学编程所必须的背景。我们还假设读者熟悉MATLAB以及初步的计算机编程基础知识。因为MATLAB是面向矩阵的语言，所以矩阵分析的基本知识也是很有帮助的。