Digital Image Processing

USING MATLAB®

Rafael C. Gonzalez
University of Tennessee

Richard E. Woods
Interapptics

Steven L. Eddins
MathWorks

Gatesmark Publishing®
A Division of Gatesmark,® LLC
www.gatesmark.com

Printed in the United States of America

Library of Congress Cataloging-in-Publication Data

Names: Gonzalez, Rafael C., author. | Woods, Richard E., author. | Eddins, Steven L., 1964- author.
Title: Digital image processing using MATLAB / Rafael C. Gonzalez, University of Tennessee, Richard E. Woods, Interapptics, Steven L. Eddins, The Mathworks, Inc.
Description: Third edition. | Knoxville : Gatesmark Publishing, 2020. | Includes bibliographical references and index. | Summary: "Update of popular Digital Image Processing text using the latest version of Matlab"-- Provided by publisher.
Identifiers: LCCN 2019041116 | ISBN 9780982085417 (hardback)
Subjects: LCSH: Image processing--Digital techniques. | Image processing--Mathematics. | MATLAB.
Classification: LCC TA1637 .G66 2020 | DDC 006.6--dc23
LC record available at https://lccn.loc.gov/2019041116

ISBN-10: 0-9820854-1-9
ISBN-13: 978-0-9820854-1-7

To Ralph
and
To Abigail
and
To Geri, Christopher, and Nicholas

Contents

Preface

When something can be read without effort, great effort has gone into its writing.

Enrique Jardiel Poncela

This edition of *Digital Image Processing Using MATLAB* is a major revision of the book. As in previous editions, the focus of this revision is based on the fact that solutions to problems in the field of digital image processing generally require extensive experimental work that involves 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, selecting a flexible, comprehensive, and well-documented software development environment plays a major role in determining 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. We wrote the first two editions of this book to meet this need. Since the last edition, both image processing and related software have experienced vigorous growth, with new developments in fields ranging from image registration and feature extraction to neural networks and deep learning, where progress in the application of convolutional neural networks just in the past seven years has been dramatic.

As in earlier editions, the most important objectives guiding us in the preparation of this edition were clarity, completeness, and relevance of the material we chose to include. As before, the discussion of every major topic is complemented by examples, and this edition is enhanced by the addition of projects at the end of every chapter. In total, the book contains 130 new MATLAB projects that complement the discussion and examples in the text. An additional objective was 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 a junior/senior curriculum in a technical discipline. Rudimentary knowledge of MATLAB is desirable, but is not a requirement because the book begins with an extensive introduction to MATLAB fundamentals and programming.

To achieve the objectives listed in the previous paragraph, 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, fully documented, and have a wide range of applications in the "real" world. The theoretical concepts in the following chapters were selected from *Digital Image Processing* by Gonzalez and Woods [2018], which has been the choice introductory textbook used by educators all over the world for over three decades. The majority of the image processing software tools we use 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 and 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 that, 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, frequency domain filtering, image restoration and reconstruction, geometric transformations and image registration, color image processing, wavelets and other transforms, image data compression, morphological image processing, image segmentation using traditional methods and active contours, feature extraction, and image pattern classification using "classical" methods, recent neural networks, and deep learning. 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, we wrote a new function as part of the instructional focus of the book. Over 200 new custom 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 algorithms and software solutions in MATLAB.

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 designed to provide support in areas such as tutorials, additional references, and image databases. New to this edition is the *DIPUM3E Support Package,* prepared in two formats to separately support students and faculty. The Student Support Package contains solutions to the projects marked with an asterisk (*) in the book, all digital images, and access to the source code for all custom functions developed in the book. The Faculty Support Package additionally contains answers to all projects and PowerPoint slides that contain all the art in the book. All purchasers of new book are eligible to download the applicable support package at no cost.

As is true of most writing efforts on technology, 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.

Acknowledgments

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, Serge Beucher, Michael W. Davidson, Courtney Esposito, Naomi Fernandes, Susan L. Forsburg, Mary Ann Freeman, Thomas R. Gest, Chris Griffin, Daniel A. Hammer, Roger Heady, Witek Jachimczyk, Brian Johnson, Mike Karr, Lisa Kempler, Chengcheng Li, Roy Lurie, Jeff Mather, Eugene McGoldrick, Ashley Mohamed, Joseph E. Pascente, David R. Pickens, Hairong Qi, Michael Robinson, Brett Shoelson, Loren Shure, Inpakala Simon, Narfi Stefansson, Sally Stowe, Alex Taylor, Craig Watson, Greg Wolodkin, Mara Yale, Alexa Zahares, and Zhifei Zhang. 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.

We appreciate Michel Kocher's many thoughtful comments and suggestions over the years on how to improve the book. We also thank Rose Kernan for her support and patience during the production of the book.

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 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 at UTK.

Gonzalez 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 technology. 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 license plates 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 massive laser disk storage 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 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.

Gonzalez is author or co-author of over 100 technical articles, two edited books, and four 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

R. E. Woods earned his B.S., M.S., and Ph.D. degrees in Electrical Engineering from the University of Tennessee, Knoxville in 1975, 1977, and 1980, respectively. He became an Assistant Professor of Electrical Engineering and Computer Science in 1981 and was recognized as a Distinguished Engineering Alumnus in 1986.

A veteran hardware and software developer, Dr. Woods has been involved in the founding of several high-technology startups, including Perceptics Corporation, where he was responsible for the development of the company's quantitative image analysis and autonomous decision-making products; MedData Interactive, a high-technology company specializing in the development of handheld computer systems for medical applications; and Interapptics, an internet-based company that designs desktop and handheld computer applications.

Dr. Woods currently serves on several nonprofit educational and media-related boards, including Johnson University, and was recently a summer English instructor at the Beijing Institute of Technology. He is the holder of a U.S. Patent in the area of digital image processing and has co-authored two textbooks, as well as numerous articles related to digital signal processing. Dr. Woods is a member of several professional societies, including Tau Beta Pi, Phi Kappa Phi, and the IEEE.

STEVEN L. EDDINS

S. L. Eddins, an electrical engineer turned software developer, has been at MathWorks since 1993, developing MATLAB and image processing products. He is a senior MATLAB designer in the areas of language evolution and the design of programming interfaces intended for use by engineers and scientists, and he holds a number of related patents. He has led software development teams responsible for general-purpose MATLAB functions, MATLAB mathematics, image processing, and image and scientific formats. He writes regularly about MATLAB and image processing at https://blogs.mathworks.com/steve.

Before joining MathWorks, Dr. Eddins was on the faculty of the Electrical Engineering and Computer Science Department at the University of Illinois at Chicago. There he taught graduate and senior classes in digital image processing, computer vision, pattern recognition, and filter design, and he performed research in 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.