



# *Digital Image Processing*

Second Edition

*Rafael C. Gonzalez*

University of Tennessee

*Richard E. Woods*

MedData Interactive



Prentice Hall  
Upper Saddle River, New Jersey 07458

**Library of Congress Cataloging-in-Publication Data**

Gonzalez, Rafael C.

Digital Image Processing / Richard E. Woods  
p. cm.

Includes bibliographical references

ISBN 0-201-18075-8

1. Digital Imaging. 2. Digital Techniques. I. Title.

TA1632.G66 2001

621.3—dc21

2001035846

CIP

Vice-President and Editorial Director, ECS: *Marcia J. Horton*

Publisher: *Tom Robbins*

Associate Editor: *Alice Dworkin*

Editorial Assistant: *Jody McDonnell*

Vice President and Director of Production and Manufacturing, ESM: *David W. Riccardi*

Executive Managing Editor: *Vince O'Brien*

Managing Editor: *David A. George*

Production Editor: *Rose Kernan*

Composition: *Prepare, Inc.*

Director of Creative Services: *Paul Belfanti*

Creative Director: *Carole Anson*

Art Director and Cover Designer: *Heather Scott*

Art Editor: *Greg Dulles*

Manufacturing Manager: *Trudy Pisciotti*

Manufacturing Buyer: *Lisa McDowell*

Senior Marketing Manager: *Jennie Burger*



© 2002 by Prentice-Hall, Inc.  
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

The author and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The author and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The author and publisher shall not be liable in any event for incidental or consequential damages in connection with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

**ISBN: 0-201-18075-8**

Pearson Education Ltd., *London*

Pearson Education Australia Pty., Limited, *Sydney*

Pearson Education Singapore, Pte. Ltd.

Pearson Education North Asia Ltd., *Hong Kong*

Pearson Education Canada, Ltd., *Toronto*

Pearson Education de Mexico, S.A. de C.V.

Pearson Education—Japan, *Tokyo*

Pearson Education Malaysia, Pte. Ltd.

Pearson Education, *Upper Saddle River, New Jersey*

# Preface

When something can be read without effort,  
great effort has gone into its writing.  
*Enrique Jardiel Poncela*

This edition is the most comprehensive revision of *Digital Image Processing* since the book first appeared in 1977. As the 1977 and 1987 editions by Gonzalez and Wintz, and the 1992 edition by Gonzalez and Woods, the present edition was prepared with students and instructors in mind. Thus, the principal objectives of the book continue to be to provide an introduction to basic concepts and methodologies for digital image processing, and to develop a foundation that can be used as the basis for further study and research in this field. To achieve these objectives, we again focused on material that we believe is fundamental and has a scope of application that is not limited to the solution of specialized problems. The mathematical complexity of the book remains at a level well within the grasp of college seniors and first-year graduate students who have introductory preparation in mathematical analysis, vectors, matrices, probability, statistics, and rudimentary computer programming.

The present edition was influenced significantly by a recent market survey conducted by Prentice Hall. The major findings of this survey were:

1. A need for more motivation in the introductory chapter regarding the spectrum of applications of digital image processing.
2. A simplification and shortening of material in the early chapters in order to “get to the subject matter” as quickly as possible.
3. A more intuitive presentation in some areas, such as image transforms and image restoration.
4. Individual chapter coverage of color image processing, wavelets, and image morphology.
5. An increase in the breadth of problems at the end of each chapter.

The reorganization that resulted in this edition is our attempt at providing a reasonable degree of balance between rigor in the presentation, the findings of the market survey, and suggestions made by students, readers, and colleagues since the last edition of the book. The major changes made in the book are as follows.

Chapter 1 was rewritten completely. The main focus of the current treatment is on examples of areas that use digital image processing. While far from exhaustive, the examples shown will leave little doubt in the reader’s mind regarding the breadth of application of digital image processing methodologies. Chapter 2 is totally new also. The focus of the presentation in this chapter is on how digital images are generated, and on the closely related concepts of

sampling, aliasing, Moiré patterns, and image zooming and shrinking. The new material and the manner in which these two chapters were reorganized address directly the first two findings in the market survey mentioned above.

Chapters 3 through 6 in the current edition cover the same concepts as Chapters 3 through 5 in the previous edition, but the scope is expanded and the presentation is totally different. In the previous edition, Chapter 3 was devoted exclusively to image transforms. One of the major changes in the book is that image transforms are now introduced when they are needed. This allowed us to begin discussion of image processing techniques much earlier than before, further addressing the second finding of the market survey. Chapters 3 and 4 in the current edition deal with image enhancement, as opposed to a single chapter (Chapter 4) in the previous edition. The new organization of this material does not imply that image enhancement is more important than other areas. Rather, we used it as an avenue to introduce spatial methods for image processing (Chapter 3), as well as the Fourier transform, the frequency domain, and image filtering (Chapter 4). Our purpose for introducing these concepts in the context of image enhancement (a subject particularly appealing to beginners) was to increase the level of intuitiveness in the presentation, thus addressing partially the third major finding in the marketing survey. This organization also gives instructors flexibility in the amount of frequency-domain material they wish to cover.

Chapter 5 also was rewritten completely in a more intuitive manner. The coverage of this topic in earlier editions of the book was based on matrix theory. Although unified and elegant, this type of presentation is difficult to follow, particularly by undergraduates. The new presentation covers essentially the same ground, but the discussion does not rely on matrix theory and is much easier to understand, due in part to numerous new examples. The price paid for this newly gained simplicity is the loss of a unified approach, in the sense that in the earlier treatment a number of restoration results could be derived from one basic formulation. On balance, however, we believe that readers (especially beginners) will find the new treatment much more appealing and easier to follow. Also, as indicated below, the old material is stored in the book Web site for easy access by individuals preferring to follow a matrix-theory formulation.

Chapter 6 dealing with color image processing is new. Interest in this area has increased significantly in the past few years as a result of growth in the use of digital images for Internet applications. Our treatment of this topic represents a significant expansion of the material from previous editions. Similarly Chapter 7, dealing with wavelets, is new. In addition to a number of signal processing applications, interest in this area is motivated by the need for more sophisticated methods for image compression, a topic that in turn is motivated by a increase in the number of images transmitted over the Internet or stored in Web servers. Chapter 8 dealing with image compression was updated to include new compression methods and standards, but its fundamental structure remains the same as in the previous edition. Several image transforms, previously covered in Chapter 3 and whose principal use is compression, were moved to this chapter.

Chapter 9, dealing with image morphology, is new. It is based on a significant expansion of the material previously included as a section in the chapter on image representation and description. Chapter 10, dealing with image segmentation, has the same basic structure as before, but numerous new examples were included and a new section on segmentation by morphological watersheds was added. Chapter 11, dealing with image representation and description, was shortened slightly by the removal of the material now included in Chapter 9. New examples were added and the Hotelling transform (description by principal components), previously included in Chapter 3, was moved to this chapter. Chapter 12 dealing with object recognition was shortened by the removal of topics dealing with knowledge-based image analysis, a topic now covered in considerable detail in a number of books which we reference in Chapters 1 and 12. Experience since the last edition of *Digital Image Processing* indicates that the new, shortened coverage of object recognition is a logical place at which to conclude the book.

Although the book is totally self-contained, we have established a companion web site (see inside front cover) designed to provide support to users of the book. For students following a formal course of study or individuals embarked on a program of self study, the site contains a number of tutorial reviews on background material such as probability, statistics, vectors, and matrices, prepared at a basic level and written using the same notation as in the book. Detailed solutions to many of the exercises in the book also are provided. For instruction, the site contains suggested teaching outlines, classroom presentation materials, laboratory experiments, and various image databases (including most images from the book). In addition, part of the material removed from the previous edition is stored in the Web site for easy download and classroom use, at the discretion of the instructor. A downloadable instructor's manual containing sample curricula, solutions to sample laboratory experiments, and solutions to all problems in the book is available to instructors who have adopted the book for classroom use.

This edition of *Digital Image Processing* is a reflection of the significant progress that has been made in this field in just the past decade. As is usual in a project such as this, progress continues after work on the manuscript stops. One of the reasons earlier versions of this book have been so well accepted throughout the world is their emphasis on fundamental concepts, an approach that, among other things, attempts to provide a measure of constancy in a rapidly-evolving body of knowledge. We have tried to observe that same principle in preparing this edition of the book.

R.C.G.  
R.E.W.

