

Preface

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

This edition of *Digital Image Processing* is a major revision of the book. As in the 1977 and 1987 editions by Gonzalez and Wintz, and the 1992, 2002, and 2008 editions by Gonzalez and Woods, this sixth-generation edition was prepared with students and instructors in mind. The principal objectives of the book continue to be to provide an introduction to basic concepts and methodologies applicable to 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 focused again on material that we believe is fundamental and whose scope of application 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, linear systems, and computer programming. The book website provides tutorials to support readers needing a review of this background material.

One of the principal reasons this book has been the world leader in its field for 40 years is the level of attention we pay to the changing educational needs of our readers. The present edition is based on an extensive survey that involved faculty, students, and independent readers of the book in 150 institutions from 30 countries. The survey revealed a need for coverage of new material that has matured since the last edition of the book. The principal findings of the survey indicated a need for:

- New material related to histogram matching.
- Expanded coverage of the fundamentals of spatial filtering.
- A more comprehensive and cohesive coverage of image transforms.
- A more complete presentation of finite differences, with a focus on edge detection.
- A discussion of clustering, superpixels, and their use in region segmentation.
- New material on active contours that includes snakes and level sets, and their use in image segmentation.
- Coverage of maximally stable extremal regions.
- Expanded coverage of feature extraction to include the Scale Invariant Feature Transform (SIFT).
- Expanded coverage of neural networks to include deep neural networks, back-propagation, deep learning, and, especially, deep convolutional neural networks.
- More homework problems at the end of the chapters.
- MATLAB computer projects.

The new and reorganized material that resulted in the present edition is our attempt at providing a reasonable balance between rigor, clarity of presentation,

and the findings of the survey. In addition to new material, earlier portions of the text were updated and clarified. This edition contains 425 new images, 135 new drawings, and 220 new exercises. For the first time, we have included MATLAB projects at the end of every chapter. In total there are 120 new MATLAB projects that cover a broad range of the material in the book. Although the solutions we provide are in MATLAB, the projects themselves are written in such a way that they can be implemented in other languages. Projects are an important addition because they will allow students to experiment with material they learn in the classroom. A large database of digital images is provided for this purpose.

New to This Edition

The highlights of this edition are as follows.

Chapter 1: Some figures were updated, and parts of the text were rewritten to correspond to changes in later chapters.

Chapter 2: Many of the sections and examples were rewritten for clarity. We added a new section dealing with random numbers and probability, with an emphasis on their application to image processing. We included 12 new examples, 31 new images, 22 new drawings, 32 new exercises, and 10 new MATLAB projects.

Chapter 3: Major revisions of the topics in this chapter include a new section on exact histogram matching. Fundamental concepts of spatial filtering were rewritten to include a discussion on separable filter kernels, expanded coverage of the properties of lowpass Gaussian kernels, and expanded coverage of highpass, bandreject, and bandpass filters, including numerous new examples that illustrate their use. In addition to revisions in the text, including 6 new examples, the chapter has 67 new images, 18 new line drawings, 31 new exercises, and 10 new MATLAB projects.

Chapter 4: Several of the sections of this chapter were revised to improve the clarity of presentation. We replaced dated graphical material with 35 new images and 4 new line drawings. We added 25 new exercises and 10 new MATLAB projects.

Chapter 5: Revisions to this chapter were limited to clarifications and a few corrections in notation. We added 6 new images, 17 new exercises, and 10 new MATLAB projects.

Chapter 6: This is a new chapter that brings together wavelets, several new transforms, and many of the image transforms that were scattered throughout the book. The emphasis of this new chapter is on the presentation of these transforms from a unified point of view. We added 24 new images, 20 new drawings, 25 new exercises and 10 new MATLAB projects.

Chapter 7: The material dealing with color image processing was moved to this chapter. Several sections were clarified, and the explanation of the CMY and CMYK color models was expanded. We added 2 new images and 10 new MATLAB projects.

Chapter 8: In addition to numerous clarifications and minor improvements to the presentation, we added 10 new MATLAB projects to this chapter.

Chapter 9: Revisions of this chapter included a complete rewrite of several sections, including redrafting of several line drawings. We added 18 new exercises and 10 new MATLAB projects.

Chapter 10: Several of the sections were rewritten for clarity. We updated the chapter by adding coverage of finite differences, K-means clustering, superpixels, and graph cuts. The new topics are illustrated with 4 new examples. In total, we added 31 new images, 3 new drawings, 8 new exercises, and 10 new MATLAB projects.

Chapter 11: This is a new chapter dealing with active contours for image segmentation, including snakes and level sets. An important feature in this chapter is that it presents a derivation of the fundamental snake equation. Similarly, we provide a derivation of the level set equation. Both equations are derived starting from basic principles, and the methods are illustrated with numerous examples. The strategy when we prepared this chapter was to bring this material to a level that could be understood by beginners in our field. To that end, we complemented the text material with 17 new examples, 141 new images, 19 new drawings, 37 new problems, and 10 new MATLAB projects.

Chapter 12: This is the chapter on feature extraction, which was moved from its 11th position in the previous edition. The chapter was updated with numerous topics, beginning with a more detailed classification of feature types and their uses. In addition to improvements in the clarity of presentation, we added coverage of slope change codes, expanded the explanation of skeletons, medial axes, and the distance transform, and added several new basic descriptors of compactness, circularity, and eccentricity. New material includes coverage of the Harris-Stephens corner detector, and a presentation of maximally stable extremal regions. A major addition to the chapter is a comprehensive discussion dealing with the Scale-Invariant Feature Transform (SIFT). The new material is complemented by 65 new images, 15 new drawings, 4 new examples, and 15 new exercises. We also added 10 new MATLAB projects.

Chapter 13: This is the image pattern classification chapter that was Chapter 12 in the previous edition. This chapter underwent a major revision to include an extensive rewrite of neural networks and deep learning, an area that has grown significantly since the last edition of the book. We added a comprehensive discussion on fully connected, deep neural networks that includes derivation of backpropagation starting from basic principles. The equations of backpropagation were expressed in “traditional” scalar terms, and then generalized into a compact set of matrix equations ideally suited for implementation of deep neural nets. The effectiveness of fully connected networks was demonstrated with several examples that included a comparison with the Bayes classifier. One of the most-requested topics in the survey was coverage of deep convolutional neural networks. We added an extensive section on this, following the same blueprint we used for deep, fully connected nets. That is, we derived the equations of backpropagation for convolutional nets, and showed how they are different from “traditional” backpropagation. We then illustrated the use of convolutional networks with simple images, and applied them to large image

databases of numerals and natural scenes. The written material is complemented by 23 new images, 28 new drawings, and 12 new exercises. We also included 10 new MATLAB projects.

Also for the first time, we have created student and faculty support packages that can be downloaded from the book website. The *Student Support Package* contains all the original images in the book, answers to selected exercises, detailed answers (including MATLAB code) to selected MATLAB projects, and instructions for using a set of utility functions that complement the projects. The *Faculty Support Package* contains solutions to all exercises and projects, teaching suggestions, and all the art in the book in the form of modifiable PowerPoint slides. One support package is made available with every new book, free of charge.

MATLAB projects are structured in a unique way that gives instructors significant flexibility in how projects are assigned. The MATLAB functions required to solve all the projects in the book are provided in executable, p-code format. These functions run just like the original functions, but the source code is not visible, and the files cannot be modified. The availability of these functions as a complete package makes it possible for projects to be assigned solely for the purpose of experimenting with image processing concepts, without having to write a single line of code. In other words, the complete set of MATLAB functions is available as a stand-alone p-code toolbox, ready to use without further development. When instructors elect to assign projects that involve MATLAB code development, we provide students enough answers to form a good base that they can expand, thus gaining experience with developing software solutions to image processing problems. Instructors have access to detailed answers to all projects.

The book website, established during the launch of the 2002 edition, continues to be a success, attracting more than 25,000 visitors each month. The site was upgraded for the launch of this edition. For more details on site features and content, see *The Book Website*, following the *Acknowledgments* section.

This edition of *Digital Image Processing* is a reflection of how the educational needs of our readers have changed since 2008. As is usual in an endeavor such as this, progress in the field continues after work on the manuscript stops. One of the reasons why this book has been so well accepted since it first appeared in 1977 is its continued emphasis on fundamental concepts that retain their relevance over time. This approach, among other things, attempts to provide a measure of stability in a rapidly evolving body of knowledge. We have tried to follow the same principle in preparing this edition of the book.

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