

Rafael C. Gonzalez  
Richard E. Woods



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# *Digital Image Processing*



*To Connie, Ralph, and Robert  
and  
To Janice, David, and Jonathan*



# *Digital Image Processing*

Second Edition

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University of Tennessee

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MedData Interactive



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# Contents

*Preface* xv

*Acknowledgements* xviii

*About the Authors* xix

## 1 Introduction 15

- 1.1 What Is Digital Image Processing? 15
- 1.2 The Origins of Digital Image Processing 17
- 1.3 Examples of Fields that Use Digital Image Processing 21
  - 1.3.1 Gamma-Ray Imaging 22
  - 1.3.2 X-ray Imaging 23
  - 1.3.3 Imaging in the Ultraviolet Band 25
  - 1.3.4 Imaging in the Visible and Infrared Bands 26
  - 1.3.5 Imaging in the Microwave Band 32
  - 1.3.6 Imaging in the Radio Band 34
  - 1.3.7 Examples in which Other Imaging Modalities Are Used 34
- 1.4 Fundamental Steps in Digital Image Processing 39
- 1.5 Components of an Image Processing System 42
  - Summary 44
  - References and Further Reading 45

## 2 Digital Image Fundamentals 34

- 2.1 Elements of Visual Perception 34
  - 2.1.1 Structure of the Human Eye 35
  - 2.1.2 Image Formation in the Eye 37
  - 2.1.3 Brightness Adaptation and Discrimination 38
- 2.2 Light and the Electromagnetic Spectrum 42
- 2.3 Image Sensing and Acquisition 45
  - 2.3.1 Image Acquisition Using a Single Sensor 47
  - 2.3.2 Image Acquisition Using Sensor Strips 48
  - 2.3.3 Image Acquisition Using Sensor Arrays 49
  - 2.3.4 A Simple Image Formation Model 50
- 2.4 Image Sampling and Quantization 52
  - 2.4.1 Basic Concepts in Sampling and Quantization 52
  - 2.4.2 Representing Digital Images 54
  - 2.4.3 Spatial and Gray-Level Resolution 57
  - 2.4.4 Aliasing and Moiré Patterns 62
  - 2.4.5 Zooming and Shrinking Digital Images 64

- 2.5 Some Basic Relationships Between Pixels 66**
  - 2.5.1 Neighbors of a Pixel 66
  - 2.5.2 Adjacency, Connectivity, Regions, and Boundaries 66
  - 2.5.3 Distance Measures 68
  - 2.5.4 Image Operations on a Pixel Basis 69
- 2.6 Linear and Nonlinear Operations 70**
  - Summary 70
  - References and Further Reading 70
  - Problems 71

## **3** *Image Enhancement in the Spatial Domain 75*

- 3.1 Background 76**
- 3.2 Some Basic Gray Level Transformations 78**
  - 3.2.1 Image Negatives 78
  - 3.2.2 Log Transformations 79
  - 3.2.3 Power-Law Transformations 80
  - 3.2.4 Piecewise-Linear Transformation Functions 85
- 3.3 Histogram Processing 88**
  - 3.3.1 Histogram Equalization 91
  - 3.3.2 Histogram Matching (Specification) 94
  - 3.3.3 Local Enhancement 103
  - 3.3.4 Use of Histogram Statistics for Image Enhancement 103
- 3.4 Enhancement Using Arithmetic/Logic Operations 108**
  - 3.4.1 Image Subtraction 110
  - 3.4.2 Image Averaging 112
- 3.5 Basics of Spatial Filtering 116**
- 3.6 Smoothing Spatial Filters 119**
  - 3.6.1 Smoothing Linear Filters 119
  - 3.6.2 Order-Statistics Filters 123
- 3.7 Sharpening Spatial Filters 125**
  - 3.7.1 Foundation 125
  - 3.7.2 Use of Second Derivatives for Enhancement—The Laplacian 128
  - 3.7.3 Use of First Derivatives for Enhancement—The Gradient 134
- 3.8 Combining Spatial Enhancement Methods 137**
  - Summary 141
  - References and Further Reading 142
  - Problems 142

## **4** *Image Enhancement in the Frequency Domain 147*

- 4.1 Background 148**



<b>4.2</b>	<b>Introduction to the Fourier Transform and the Frequency Domain</b>	<b>149</b>
4.2.1	The One-Dimensional Fourier Transform and its Inverse	150
4.2.2	The Two-Dimensional DFT and Its Inverse	154
4.2.3	Filtering in the Frequency Domain	156
4.2.4	Correspondence between Filtering in the Spatial and Frequency Domains	161
<b>4.3</b>	<b>Smoothing Frequency-Domain Filters</b>	<b>167</b>
4.3.1	Ideal Lowpass Filters	167
4.3.2	Butterworth Lowpass Filters	173
4.3.3	Gaussian Lowpass Filters	175
4.3.4	Additional Examples of Lowpass Filtering	178
<b>4.4</b>	<b>Sharpening Frequency Domain Filters</b>	<b>180</b>
4.4.1	Ideal Highpass Filters	182
4.4.2	Butterworth Highpass Filters	183
4.4.3	Gaussian Highpass Filters	184
4.4.4	The Laplacian in the Frequency Domain	185
4.4.5	Unsharp Masking, High-Boost Filtering, and High-Frequency Emphasis Filtering	187
<b>4.5</b>	<b>Homomorphic Filtering</b>	<b>191</b>
<b>4.6</b>	<b>Implementation</b>	<b>194</b>
4.6.1	Some Additional Properties of the 2-D Fourier Transform	194
4.6.2	Computing the Inverse Fourier Transform Using a Forward Transform Algorithm	198
4.6.3	More on Periodicity: the Need for Padding	199
4.6.4	The Convolution and Correlation Theorems	205
4.6.5	Summary of Properties of the 2-D Fourier Transform	208
4.6.6	The Fast Fourier Transform	208
4.6.7	Some Comments on Filter Design	213
	<b>Summary</b>	<b>214</b>
	<b>References</b>	<b>214</b>
	<b>Problems</b>	<b>215</b>

## 5 *Image Restoration* 220

<b>5.1</b>	<b>A Model of the Image Degradation/Restoration Process</b>	<b>221</b>
<b>5.2</b>	<b>Noise Models</b>	<b>222</b>
5.2.1	Spatial and Frequency Properties of Noise	222
5.2.2	Some Important Noise Probability Density Functions	222
5.2.3	Periodic Noise	227
5.2.4	Estimation of Noise Parameters	227
<b>5.3</b>	<b>Restoration in the Presence of Noise Only—Spatial Filtering</b>	<b>230</b>
5.3.1	Mean Filters	231
5.3.2	Order-Statistics Filters	233
5.3.3	Adaptive Filters	237

<b>5.4</b>	<b>Periodic Noise Reduction by Frequency Domain Filtering</b>	<b>243</b>
5.4.1	Bandreject Filters	244
5.4.2	Bandpass Filters	245
5.4.3	Notch Filters	246
5.4.4	Optimum Notch Filtering	248
<b>5.5</b>	<b>Linear, Position-Invariant Degradations</b>	<b>254</b>
<b>5.6</b>	<b>Estimating the Degradation Function</b>	<b>256</b>
5.6.1	Estimation by Image Observation	256
5.6.2	Estimation by Experimentation	257
5.6.3	Estimation by Modeling	258
<b>5.7</b>	<b>Inverse Filtering</b>	<b>261</b>
<b>5.8</b>	<b>Minimum Mean Square Error (Wiener) Filtering</b>	<b>262</b>
<b>5.9</b>	<b>Constrained Least Squares Filtering</b>	<b>266</b>
<b>5.10</b>	<b>Geometric Mean Filter</b>	<b>270</b>
<b>5.11</b>	<b>Geometric Transformations</b>	<b>270</b>
5.11.1	Spatial Transformations	271
5.11.2	Gray-Level Interpolation	272
	<b>Summary</b>	<b>276</b>
	<b>References and Further Reading</b>	<b>277</b>
	<b>Problems</b>	<b>278</b>

## 6 *Color Image Processing* 282

<b>6.1</b>	<b>Color Fundamentals</b>	<b>283</b>
<b>6.2</b>	<b>Color Models</b>	<b>289</b>
6.2.1	The RGB Color Model	290
6.2.2	The CMY and CMYK Color Models	294
6.2.3	The HSI Color Model	295
<b>6.3</b>	<b>Pseudocolor Image Processing</b>	<b>302</b>
6.3.1	Intensity Slicing	303
6.3.2	Gray Level to Color Transformations	308
<b>6.4</b>	<b>Basics of Full-Color Image Processing</b>	<b>313</b>
<b>6.5</b>	<b>Color Transformations</b>	<b>315</b>
6.5.1	Formulation	315
6.5.2	Color Complements	318
6.5.3	Color Slicing	320
6.5.4	Tone and Color Corrections	322
6.5.5	Histogram Processing	326
<b>6.6</b>	<b>Smoothing and Sharpening</b>	<b>327</b>
6.6.1	Color Image Smoothing	328
6.6.2	Color Image Sharpening	330
<b>6.7</b>	<b>Color Segmentation</b>	<b>331</b>
6.7.1	Segmentation in HSI Color Space	331
6.7.2	Segmentation in RGB Vector Space	333
6.7.3	Color Edge Detection	335

- 6.8 Noise in Color Images 339
- 6.9 Color Image Compression 342
  - Summary 343
  - References and Further Reading 344
  - Problems 344

## 7 *Wavelets and Multiresolution Processing* 349

- 7.1 Background 350
  - 7.1.1 Image Pyramids 351
  - 7.1.2 Subband Coding 354
  - 7.1.3 The Haar Transform 360
- 7.2 Multiresolution Expansions 363
  - 7.2.1 Series Expansions 364
  - 7.2.2 Scaling Functions 365
  - 7.2.3 Wavelet Functions 369
- 7.3 Wavelet Transforms in One Dimension 372
  - 7.3.1 The Wavelet Series Expansions 372
  - 7.3.2 The Discrete Wavelet Transform 375
  - 7.3.3 The Continuous Wavelet Transform 376
- 7.4 The Fast Wavelet Transform 379
- 7.5 Wavelet Transforms in Two Dimensions 386
- 7.6 Wavelet Packets 394
  - Summary 402
  - References and Further Reading 404
  - Problems 404

## 8 *Image Compression* 409

- 8.1 Fundamentals 411
  - 8.1.1 Coding Redundancy 412
  - 8.1.2 Interpixel Redundancy 414
  - 8.1.3 Psychovisual Redundancy 417
  - 8.1.4 Fidelity Criteria 419
- 8.2 Image Compression Models 421
  - 8.2.1 The Source Encoder and Decoder 421
  - 8.2.2 The Channel Encoder and Decoder 423
- 8.3 Elements of Information Theory 424
  - 8.3.1 Measuring Information 424
  - 8.3.2 The Information Channel 425
  - 8.3.3 Fundamental Coding Theorems 430
  - 8.3.4 Using Information Theory 437
- 8.4 Error-Free Compression 440
  - 8.4.1 Variable-Length Coding 440

8.4.2	LZW Coding	446
8.4.3	Bit-Plane Coding	448
8.4.4	Lossless Predictive Coding	456
<b>8.5</b>	<b>Lossy Compression</b>	<b>459</b>
8.5.1	Lossy Predictive Coding	459
8.5.2	Transform Coding	467
8.5.3	Wavelet Coding	486
<b>8.6</b>	<b>Image Compression Standards</b>	<b>492</b>
8.6.1	Binary Image Compression Standards	493
8.6.2	Continuous Tone Still Image Compression Standards	498
8.6.3	Video Compression Standards	510
	<b>Summary</b>	<b>513</b>
	<b>References and Further Reading</b>	<b>513</b>
	<b>Problems</b>	<b>514</b>

## 9 *Morphological Image Processing* 519

<b>9.1</b>	<b>Preliminaries</b>	<b>520</b>
9.1.1	Some Basic Concepts from Set Theory	520
9.1.2	Logic Operations Involving Binary Images	522
<b>9.2</b>	<b>Dilation and Erosion</b>	<b>523</b>
9.2.1	Dilation	523
9.2.2	Erosion	525
<b>9.3</b>	<b>Opening and Closing</b>	<b>528</b>
<b>9.4</b>	<b>The Hit-or-Miss Transformation</b>	<b>532</b>
<b>9.5</b>	<b>Some Basic Morphological Algorithms</b>	<b>534</b>
9.5.1	Boundary Extraction	534
9.5.2	Region Filling	535
9.5.3	Extraction of Connected Components	536
9.5.4	Convex Hull	539
9.5.5	Thinning	541
9.5.6	Thickening	541
9.5.7	Skeletons	543
9.5.8	Pruning	545
9.5.9	Summary of Morphological Operations on Binary Images	547
<b>9.6</b>	<b>Extensions to Gray-Scale Images</b>	<b>550</b>
9.6.1	Dilation	550
9.6.2	Erosion	552
9.6.3	Opening and Closing	554
9.6.4	Some Applications of Gray-Scale Morphology	556
	<b>Summary</b>	<b>560</b>
	<b>References and Further Reading</b>	<b>560</b>
	<b>Problems</b>	<b>560</b>



## 10 *Image Segmentation* 567

- 10.1 Detection of Discontinuities** 568
  - 10.1.1 Point Detection 569
  - 10.1.2 Line Detection 570
  - 10.1.3 Edge Detection 572
- 10.2 Edge Linking and Boundary Detection** 585
  - 10.2.1 Local Processing 585
  - 10.2.2 Global Processing via the Hough Transform 587
  - 10.2.3 Global Processing via Graph-Theoretic Techniques 591
- 10.3 Thresholding** 595
  - 10.3.1 Foundation 595
  - 10.3.2 The Role of Illumination 596
  - 10.3.3 Basic Global Thresholding 598
  - 10.3.4 Basic Adaptive Thresholding 600
  - 10.3.5 Optimal Global and Adaptive Thresholding 602
  - 10.3.6 Use of Boundary Characteristics for Histogram Improvement and Local Thresholding 608
  - 10.3.7 Thresholds Based on Several Variables 611
- 10.4 Region-Based Segmentation** 612
  - 10.4.1 Basic Formulation 612
  - 10.4.2 Region Growing 613
  - 10.4.3 Region Splitting and Merging 615
- 10.5 Segmentation by Morphological Watersheds** 617
  - 10.5.1 Basic Concepts 617
  - 10.5.2 Dam Construction 620
  - 10.5.3 Watershed Segmentation Algorithm 622
  - 10.5.4 The Use of Markers 624
- 10.6 The Use of Motion in Segmentation** 626
  - 10.6.1 Spatial Techniques 626
  - 10.6.2 Frequency Domain Techniques 630
- Summary** 634
- References and Further Reading** 634
- Problems** 636

## 11 *Representation and Description* 643

- 11.1 Representation** 644
  - 11.1.1 Chain Codes 644
  - 11.1.2 Polygonal Approximations 646
  - 11.1.3 Signatures 648
  - 11.1.4 Boundary Segments 649
  - 11.1.5 Skeletons 650

<b>11.2</b>	<b>Boundary Descriptors</b>	<b>653</b>
11.2.1	Some Simple Descriptors	653
11.2.2	Shape Numbers	654
11.2.3	Fourier Descriptors	655
11.2.4	Statistical Moments	659
<b>11.3</b>	<b>Regional Descriptors</b>	<b>660</b>
11.3.1	Some Simple Descriptors	661
11.3.2	Topological Descriptors	661
11.3.3	Texture	665
11.3.4	Moments of Two-Dimensional Functions	672
<b>11.4</b>	<b>Use of Principal Components for Description</b>	<b>675</b>
<b>11.5</b>	<b>Relational Descriptors</b>	<b>683</b>
	Summary	687
	References and Further Reading	687
	Problems	689

## 12 *Object Recognition* 693

<b>12.1</b>	<b>Patterns and Pattern Classes</b>	<b>693</b>
<b>12.2</b>	<b>Recognition Based on Decision-Theoretic Methods</b>	<b>698</b>
12.2.1	Matching	698
12.2.2	Optimum Statistical Classifiers	704
12.2.3	Neural Networks	712
<b>12.3</b>	<b>Structural Methods</b>	<b>732</b>
12.3.1	Matching Shape Numbers	732
12.3.2	String Matching	734
12.3.3	Syntactic Recognition of Strings	735
12.3.4	Syntactic Recognition of Trees	740
	Summary	750
	References and Further Reading	750
	Problems	750

*Bibliography* 755

*Index* 779

# 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.

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*R.C.G*

*R.E.W*



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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 Engineering Department at 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 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 Nat'l Award for Excellence in Commercial Image Processing; the 1989 B. Otto Wheelley 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 500 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 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.



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