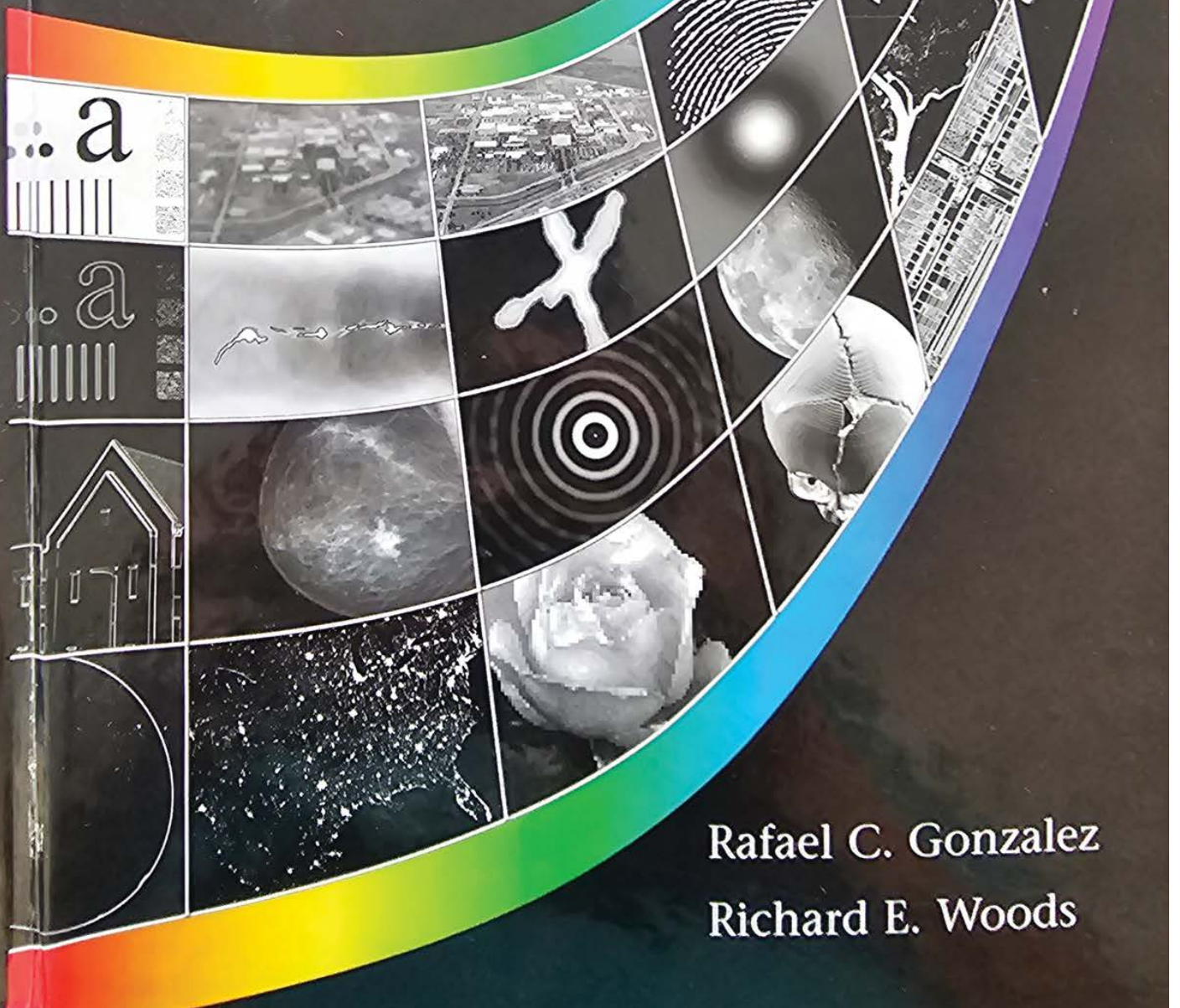


Digital Image Processing

Second Edition



Rafael C. Gonzalez
Richard E. Woods

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Digital Image Processing

Prof. Dr. C. Gonzalez

Richard E. Woods



Digital Image Processing

Second Edition

Rafael C. Gonzalez

University of Tennessee

Richard E. Woods

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

Contents

Preface xv

Acknowledgements xviii

About the Authors xix

1 Introduction 1

- 1.1 What Is Digital Image Processing? 1
- 1.2 The Origins of Digital Image Processing 3
- 1.3 Examples of Fields that Use Digital Image Processing 7
 - 1.3.1 Gamma-Ray Imaging 8
 - 1.3.2 X-ray Imaging 9
 - 1.3.3 Imaging in the Ultraviolet Band 11
 - 1.3.4 Imaging in the Visible and Infrared Bands 12
 - 1.3.5 Imaging in the Microwave Band 18
 - 1.3.6 Imaging in the Radio Band 20
 - 1.3.7 Examples in which Other Imaging Modalities Are Used 20
- 1.4 Fundamental Steps in Digital Image Processing 25
- 1.5 Components of an Image Processing System 28
 - Summary 30
 - References and Further Reading 31

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

4.2	Introduction to the Fourier Transform and the Frequency Domain	149
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
4.3	Smoothing Frequency-Domain Filters	167
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
4.4	Sharpening Frequency Domain Filters	180
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
4.5	Homomorphic Filtering	191
4.6	Implementation	194
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
	Summary	214
	References	214
	Problems	215

5 *Image Restoration* 220

5.1	A Model of the Image Degradation/Restoration Process	221
5.2	Noise Models	222
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
5.3	Restoration in the Presence of Noise Only—Spatial Filtering	230
5.3.1	Mean Filters	231
5.3.2	Order-Statistics Filters	233
5.3.3	Adaptive Filters	237

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

6 *Color Image Processing* 282

6.1	Color Fundamentals	283
6.2	Color Models	289
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
6.3	Pseudocolor Image Processing	302
6.3.1	Intensity Slicing	303
6.3.2	Gray Level to Color Transformations	308
6.4	Basics of Full-Color Image Processing	313
6.5	Color Transformations	315
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
6.6	Smoothing and Sharpening	327
6.6.1	Color Image Smoothing	328
6.6.2	Color Image Sharpening	330
6.7	Color Segmentation	331
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
8.5	Lossy Compression	459
8.5.1	Lossy Predictive Coding	459
8.5.2	Transform Coding	467
8.5.3	Wavelet Coding	486
8.6	Image Compression Standards	492
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
	Summary	513
	References and Further Reading	513
	Problems	514

9 *Morphological Image Processing* 519

9.1	Preliminaries	520
9.1.1	Some Basic Concepts from Set Theory	520
9.1.2	Logic Operations Involving Binary Images	522
9.2	Dilation and Erosion	523
9.2.1	Dilation	523
9.2.2	Erosion	525
9.3	Opening and Closing	528
9.4	The Hit-or-Miss Transformation	532
9.5	Some Basic Morphological Algorithms	534
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	54
9.6	Extensions to Gray-Scale Images	550
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
	Summary	560
	References and Further Reading	560
	Problems	560

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

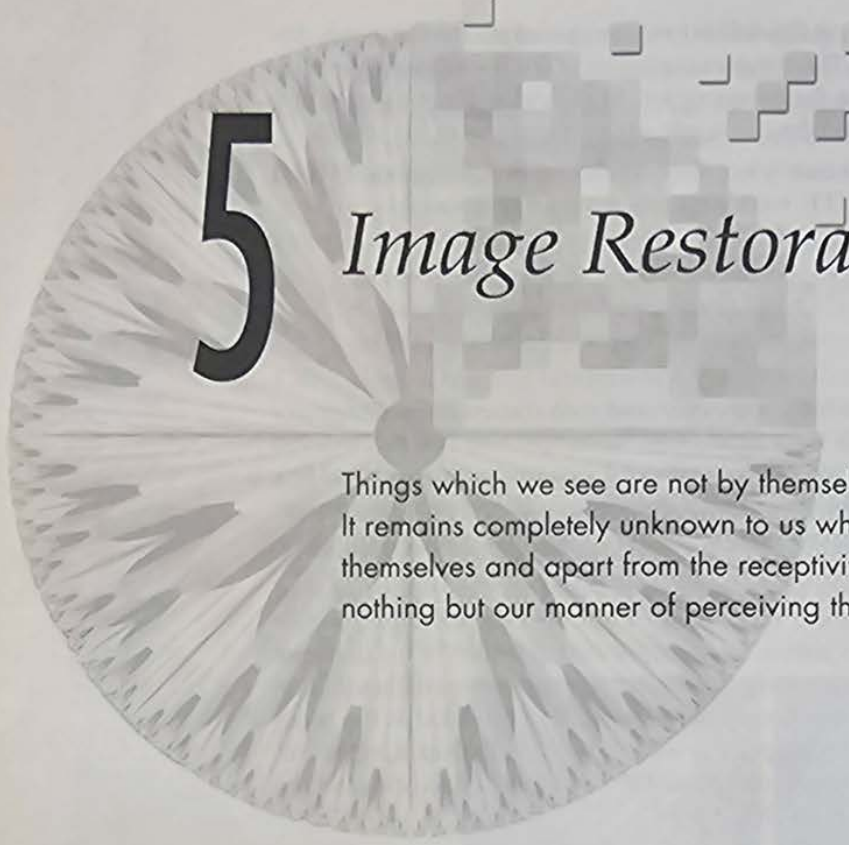
11.2 Boundary Descriptors	653
11.2.1 Some Simple Descriptors	653
11.2.2 Shape Numbers	654
11.2.3 Fourier Descriptors	655
11.2.4 Statistical Moments	659
11.3 Regional Descriptors	660
11.3.1 Some Simple Descriptors	661
11.3.2 Topological Descriptors	661
11.3.3 Texture	665
11.3.4 Moments of Two-Dimensional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

12 *Object Recognition* 693

12.1 Patterns and Pattern Classes	693
12.2 Recognition Based on Decision-Theoretic Methods	698
12.2.1 Matching	698
12.2.2 Optimum Statistical Classifiers	704
12.2.3 Neural Networks	712
12.3 Structural Methods	732
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



5 Image Restoration

Things which we see are not by themselves what we see...
It remains completely unknown to us what the objects may be by themselves and apart from the receptivity of our senses. We know nothing but our manner of perceiving them.

Immanuel Kant

Preview

As in image enhancement, the ultimate goal of restoration techniques is to improve an image in some predefined sense. Although there are areas of overlap, image enhancement is largely a subjective process, while image restoration is for the most part an objective process. Restoration attempts to reconstruct or recover an image that has been degraded by using a priori knowledge of the degradation phenomenon. Thus restoration techniques are oriented toward modeling the degradation and applying the inverse process in order to recover the original image.

This approach usually involves formulating a criterion of goodness that will yield an optimal estimate of the desired result. By contrast, enhancement techniques basically are heuristic procedures designed to manipulate an image in order to take advantage of the psychophysical aspects of the human visual system. For example, contrast stretching is considered an enhancement technique because it is based primarily on the pleasing aspects it might present to the viewer, whereas removal of image blur by applying a deblurring function is considered a restoration technique.

The material developed in this chapter is strictly introductory. We consider the restoration problem only from the point where a degraded, *digital* image is given; thus we consider topics dealing with sensor, digitizer, and display degradations only superficially. These subjects, although of importance in the overall treatment of image restoration applications, are beyond the scope of the present discussion.

As in Chapters 3 and 4, some restoration techniques are best formulated in the spatial domain, while others are better suited for the frequency domain. For example, spatial processing is applicable when the only degradation is additive noise. On the other hand, degradations such as image blur are difficult to approach in the spatial domain using small masks. In this case, frequency domain filters based on various criteria of optimality are the approaches of choice. These filters also take into account the presence of noise. As in Chapter 4 (see comments in Section 4.6.7), a restoration filter that solves a given application in the frequency domain often is used as the basis for generating a digital filter that will be more suitable for routine operation using a hardware/firmware implementation.

5.1 A Model of the Image Degradation/Restoration Process

As Fig. 5.1 shows, the degradation process is modeled in this chapter as a degradation function that, together with an additive noise term, operates on an input image $f(x, y)$ to produce a degraded image $g(x, y)$. Given $g(x, y)$, some knowledge about the degradation function H , and some knowledge about the additive noise term $\eta(x, y)$, the objective of restoration is to obtain an estimate $\hat{f}(x, y)$ of the original image. We want the estimate to be as close as possible to the original input image and, in general, the more we know about H and η , the closer $\hat{f}(x, y)$ will be to $f(x, y)$. The approach used throughout most of this chapter is based on various types of image restoration filters.

It is shown in Section 5.5 that if H is a linear, position-invariant process, then the degraded image is given in the *spatial domain* by

$$g(x, y) = h(x, y) * f(x, y) + \eta(x, y) \quad (5.1-1)$$

where $h(x, y)$ is the spatial representation of the degradation function and, as in Chapter 4, the symbol “*” indicates convolution. We know from the discussion in Sections 4.2.4 and 4.6.4 that convolution in the spatial domain is equal to multiplication in the frequency domain, so we may write the model in Eq. (5.1-1) in an equivalent *frequency domain* representation:

$$G(u, v) = H(u, v)F(u, v) + N(u, v) \quad (5.1-2)$$

where the terms in capital letters are the Fourier transforms of the corresponding terms in Eq. (5.1-1). These two equations are the bases for most of the material in this chapter.

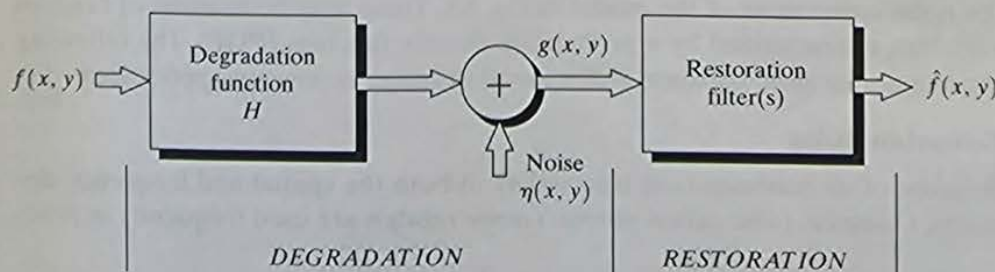


FIGURE 5.1 A model of the image degradation/restoration process.

In the following three sections, we assume that H is the identity operator, and we deal only with degradations due to noise. Beginning in Section 5.6 we consider a number of important image degradation functions and look at several methods for image restoration in the presence of both H and η .

5.2 Noise Models

The principal sources of noise in digital images arise during image acquisition (digitization) and/or transmission. The performance of imaging sensors is affected by a variety of factors, such as environmental conditions during image acquisition, and by the quality of the sensing elements themselves. For instance, in acquiring images with a CCD camera, light levels and sensor temperature are major factors affecting the amount of noise in the resulting image. Images are corrupted during transmission principally due to interference in the channel used for transmission. For example, an image transmitted using a wireless network might be corrupted as a result of lightning or other atmospheric disturbance.

5.2.1 Spatial and Frequency Properties of Noise

Relevant to our discussion are parameters that define the spatial characteristics of noise, and whether the noise is correlated with the image. Frequency properties refer to the frequency content of noise in the Fourier sense (i.e., as opposed to the electromagnetic spectrum). For example, when the Fourier spectrum of noise is constant, the noise usually is called *white noise*. This terminology is a carry-over from the physical properties of white light, which contains nearly all frequencies in the visible spectrum in equal proportions. From the discussion in Chapter 4, it is not difficult to show that the Fourier spectrum of a function containing all frequencies in equal proportions is a constant.

With the exception of spatially periodic noise (Section 5.2.3), we assume in this chapter that noise is independent of spatial coordinates, and that it is uncorrelated with respect to the image itself (that is, there is no correlation between pixel values and the values of noise components). Although these assumptions are at least partially invalid in some applications (quantum-limited imaging, such as in X-ray and nuclear-medicine imaging, is a good example), the complexities of dealing with spatially dependent and correlated noise are beyond the scope of our discussion.

5.2.2 Some Important Noise Probability Density Functions

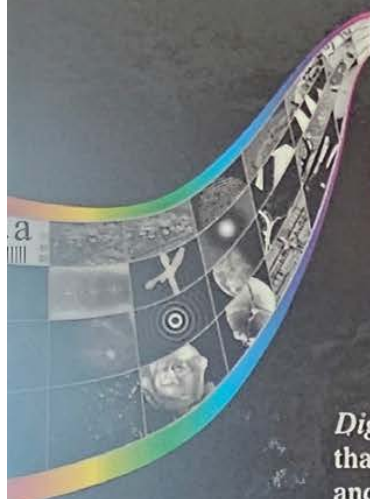
Based on the assumptions in the previous section, the *spatial* noise descriptor with which we shall be concerned is the statistical behavior of the gray-level values in the noise component of the model in Fig. 5.1. These may be considered random variables, characterized by a probability density function (PDF). The following are among the most common PDFs found in image processing applications.

Gaussian noise

Because of its mathematical tractability in both the spatial and frequency domains, Gaussian (also called *normal*) noise models are used frequently in prac-



See inside front cover
Consult the book web site
for a brief review of prob-
ability theory.



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Digital Image Processing has been the leading textbook in its field for more than 20 years. As was the case with 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. The material is timely, highly readable, and illustrated with numerous examples of practical significance. All mainstream areas of image processing are covered, including a totally revised introduction and discussion of image fundamentals, image enhancement in the spatial and frequency domains, restoration, color image processing, wavelets, image compression, morphology, segmentation, and image description. Coverage concludes with a discussion of the fundamentals of object recognition.

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