

Contents

1	Introduction	1
1.1	Digital Image Processing — A New Research Tool	1
1.2	Components of an Image Processing System	2
1.2.1	Image Sensors	2
1.2.2	Image Storage	6
1.2.3	Image Processing Speed	8
1.3	Human and Computer Vision	8
1.4	Examples of Scientific Applications	12
1.5	Hierarchy of Image Processing Operations	15
1.6	Image Processing and Computer Graphics	18
2	Image Formation and Digitization	19
2.1	Interaction between Light and Matter	19
2.1.1	Introduction	19
2.1.2	Opaque Surfaces	20
2.1.3	Volumes	21
2.1.4	Light Sources	22
2.1.5	Reflection	22
2.2	Image formation	22
2.2.1	World and Camera Coordinates	23
2.2.2	Pinhole Camera Model: Perspective Projection	24
2.2.3	Homogeneous Coordinates	26
2.2.4	Geometric Distortion	28
2.2.5	Depth of Focus	29
2.2.6	3-D Point Spread Function	31
2.2.7	Optical Transfer Function	33
2.2.8	Cross Sectional Imaging	37
2.2.9	Stereoscopy	38
2.2.10	Tomography	39
2.3	Digitization	40
2.3.1	Image matrix	40
2.3.2	Moiré-Effect and Aliasing	43
2.3.3	The Sampling Theorem	45
2.3.4	Reconstruction from Samples	50
2.3.5	Standard Sampling	51

3	Space and Wave Number Domain	53
3.1	Introduction	53
3.2	The Discrete Fourier transform (DFT)	54
3.2.1	The one-dimensional DFT	54
3.2.2	The Two-Dimensional DFT	56
3.2.3	Periodicity	57
3.2.4	Symmetry	57
3.2.5	Dynamical Range of the DFT	60
3.2.6	Phase and Amplitude	61
3.3	Discrete Unitary Transforms	63
3.3.1	General Properties	63
3.3.2	Further Examples for Unitary Transforms	65
3.4	Fast Algorithms for Unitary Transforms	67
3.4.1	Importance of Fast Algorithms	67
3.4.2	The 1-D Radix-2 FFT Algorithms	68
3.4.3	Other 1-D FFT Algorithms	72
3.4.4	Multidimensional FFT Algorithms	75
4	Pixels	77
4.1	Introduction	77
4.2	Random Variables	77
4.2.1	Basics	77
4.2.2	Quantization	81
4.2.3	Histograms	83
4.3	Point Operations	86
4.3.1	Homogeneous Point Operations	86
4.3.2	Look-Up Tables	86
4.3.3	Inhomogeneous Point Operations	91
4.4	Dyadic LUT Operations	94
4.5	Correlations and Spectra	95
4.5.1	Random Fields	95
4.5.2	Correlations and Covariances	95
4.5.3	Spectra and Coherence	97
5	Neighborhoods	100
5.1	Combining Pixels	100
5.1.1	Linear Filtering	101
5.1.2	Recursive Filters and Linear Systems	103
5.1.3	Rank Value Filtering	106
5.2	Linear Shift-Invariant Filters	107
5.2.1	Linearity	108
5.2.2	Shift Invariance	109
5.2.3	Impulse Response, Transfer Function, and Eigenfunctions	109
5.2.4	Symmetry	111
5.2.5	General Properties of Linear Shift-Invariant Operators	114

6	Mean and Edges	117
6.1	Smoothing	117
6.1.1	Box Filters	117
6.1.2	Binomial Filters	122
6.1.3	Recursive Smoothing Filters	128
6.1.4	Median Filter	131
6.2	Edge Detection	134
6.2.1	First-Order Derivative Operators	135
6.2.2	Laplace Filter	138
6.3	Filter Design	140
6.3.1	Filter Nets	142
6.3.2	Filter Decomposition	146
6.3.3	Smoothing Operators	147
6.3.4	Bandpass Filters; DoG and LoG Filter	153
6.3.5	Derivative Operators	155
7	Local Orientation	157
7.1	Introduction	157
7.1.1	Vectorial Representation of Local Orientation	159
7.1.2	Color Coding of Vectorial Image Features	159
7.2	The Quadrature Filter Set Method	160
7.2.1	Directional Quadrature Filters	160
7.2.2	Vectorial Filter Response Addition	162
7.3	The Tensor Method	164
7.3.1	Analogy: The Inertia Tensor	166
7.3.2	Eigenvalue Analysis of the 2-D Inertia Tensor	167
7.3.3	Computing the Inertia Tensor in the Space Domain	168
7.3.4	Examples and Applications	170
8	Scales	173
8.1	Multigrid Data Structures	173
8.2	Gauss and Laplace Pyramids	174
8.2.1	Introduction	174
8.2.2	Algorithms for Pyramidal Decomposition	177
8.2.3	Filters for Pyramid Formation	180
8.2.4	Interpolation	180
9	Texture	185
9.1	Introduction	185
9.2	Rotation and Scale Invariant Texture Features	188
9.2.1	Local Variance	188
9.3	Rotation and Scale Variant Texture Features	190
9.3.1	Local Orientation	190
9.3.2	Local Wave Number	190
9.3.3	Pyramidal Texture Analysis	190
9.4	Fractal Description of Texture	192

10 Segmentation	193
10.1 Introduction	193
10.2 Pixel-Based Methods	193
10.3 Region-Based Methods	195
10.4 Edge-Based Methods	198
11 Shape	200
11.1 Introduction	200
11.2 Morphological Operators	200
11.2.1 Neighborhood Operations on Binary Images	200
11.2.2 General Properties of Morphological Operations	202
11.2.3 Further Morphological Operations	204
11.3 Representation of Shape	208
11.3.1 Chain Code	208
11.3.2 Run-length Code	209
11.3.3 Quadrees	210
11.4 Shape Parameters	212
11.4.1 Simple Geometric Parameters	212
11.4.2 Moment-based Shape Features	214
11.4.3 Fourier Descriptors	216
12 Classification	219
12.1 Introduction	219
12.2 Feature Space; Clusters	221
12.3 Feature Selection; Principal-Axes Transform	223
12.4 Classification Techniques	225
12.5 Application	226
13 Reconstruction from Projections	231
13.1 Introduction	231
13.2 Focus Series	233
13.2.1 Reconstruction of Surfaces in Space	233
13.2.2 Reconstruction by Inverse Filtering	234
13.2.3 Confocal Laser Scanning Microscopy	237
13.3 Reconstruction of Tomographic Images	239
13.3.1 Introduction	239
13.3.2 Radon Transform and Fourier Slice Theorem	240
13.3.3 Filtered Back Projection	241
13.3.4 Algebraic Reconstruction	245
14 Motion	253
14.1 Introduction	253
14.1.1 Gray Value Changes	254
14.1.2 The Aperture Problem	257
14.1.3 The Correspondence Problem	257
14.1.4 Motion Analysis and 3-D Reconstruction	259
14.2 Motion Kinematics	259
14.2.1 Mass points	261
14.2.2 Deformable Objects	263

14.2.3	Kinematics of Projected Motion	266
14.3	Motion Dynamics	268
14.4	Motion Models	269
14.4.1	Motion of Points	270
14.4.2	Motion of Planar Surfaces	272
14.4.3	Motion in Cross-Sectional Images	274
15	Displacement Vectors	275
15.1	Introduction	275
15.2	Differential Methods	276
15.2.1	Optical Flux	276
15.2.2	Least Squares Solution of the Aperture Problem	279
15.2.3	Differential Geometric Modeling	286
15.3	Correlation Methods	289
15.3.1	Principle	290
15.3.2	Fast Implementation	291
15.3.3	Monotony Operator	293
15.3.4	Signum of the Laplace Operator	296
16	Displacement Vector Fields	297
16.1	Introduction	297
16.2	Determination of DVF by Variational Calculus	298
16.2.1	General Approach	298
16.2.2	Differential Method as a Minimal Problem	299
16.3	Smooth Displacement Vector Fields	300
16.3.1	Smoothness Constraints	300
16.3.2	Elasticity Models	302
16.3.3	Network Models	304
16.3.4	Diffusion Models	308
16.4	Controlling Smoothness	309
16.4.1	Smooth Displacement Vector Fields	310
16.4.2	Edge-oriented Smoothness	313
16.4.3	Region-limited Smoothness	315
16.4.4	Oriented Smoothness	315
16.5	Summary	316
17	Space-Time Images	318
17.1	Motion is Orientation	318
17.2	Motion in Fourier Domain	321
17.3	Velocity Filtering	323
17.3.1	Projection Filters	324
17.3.2	Gabor Filters	326
17.4	1-D Motion Determination	327
17.4.1	Conversion of the Differential Method into a Filter Method	327
17.4.2	The Tensor Method	330
17.4.3	The Quadrature Filter Set Method	331
17.4.4	The Phase Method	332
17.4.5	Accuracy of Motion Determination	334
17.5	2-D Motion Determination	336

17.5.1	The Quadrature Filter Set Method	336
17.5.2	The Tensor Method	337
A	Mathematical Preliminaries	341
A.1	Matrix Algebra	341
A.1.1	Definitions	341
A.1.2	The Overdetermined Discrete Inverse Problem	342
A.1.3	Suggested Further Readings	344
A.2	Fourier Transformation	344
A.2.1	Definition	344
A.2.2	Properties of the Fourier Transform	345
A.2.3	Important Fourier Transform Pairs	346
A.2.4	Suggested Further Readings	346
A.3	Discrete Fourier transform (DFT)	346
A.3.1	Definition	346
A.3.2	Important Properties	347
A.3.3	Important Transform Pairs	348
A.3.4	Suggested Further Readings	348
B	PC-Based Image Processing Systems	349
B.1	Overview	349
B.2	Video Input	350
B.3	Frame Buffer	353
B.4	Video Output	354
B.5	Dedicated Image Processing Hardware	355
B.5.1	Process Window: Area-of-Interest	356
B.5.2	Arithmetic Pipeline Processors	357
B.5.3	Filter processors	357
B.5.4	Histogram and Feature Extractors	358
B.5.5	Parallel Processing in the Video Pipeline	358
B.6	Programmable Systems	359
	Bibliography	370
	Index	376