

# Contents

## I Foundation

<b>1 Applications and Tools</b>	3
1.1 A Tool for Science and Technique . . . . .	3
1.2 Examples of Applications . . . . .	4
1.3 Hierarchy of Image Processing Operations . . . . .	15
1.4 Image Processing and Computer Graphics . . . . .	17
1.5 Cross-disciplinary Nature of Image Processing . . . . .	17
1.6 Human and Computer Vision . . . . .	18
1.7 Components of an Image Processing System . . . . .	21
1.8 <i>Exercises</i> . . . . .	26
1.9 <i>Further Readings</i> . . . . .	28
<b>2 Image Representation</b>	31
2.1 Introduction . . . . .	31
2.2 Spatial Representation of Digital Images . . . . .	31
2.3 Wave Number Space and Fourier Transform . . . . .	41
2.4 <i>Discrete Unitary Transforms</i> . . . . .	63
2.5 <i>Fast Algorithms for Unitary Transforms</i> . . . . .	67
2.6 <i>Exercises</i> . . . . .	77
2.7 <i>Further Readings</i> . . . . .	80
<b>3 Random Variables and Fields</b>	81
3.1 Introduction . . . . .	81
3.2 Random Variables . . . . .	83
3.3 Multiple Random Variables . . . . .	87
3.4 Probability Density Functions . . . . .	91
3.5 <i>Stochastic Processes and Random Fields</i> . . . . .	98
3.6 <i>Exercises</i> . . . . .	102
3.7 <i>Further Readings</i> . . . . .	104
<b>4 Neighborhood Operations</b>	105
4.1 Basic Properties and Purpose . . . . .	105
4.2 Linear Shift-Invariant Filters . . . . .	108
4.3 Rank Value Filters . . . . .	119
4.4 <i>LSI-Filters: Further Properties</i> . . . . .	120
4.5 <i>Recursive Filters</i> . . . . .	122

4.6	<i>Exercises</i> . . . . .	131
4.7	<i>Further Readings</i> . . . . .	134
<b>5</b>	<b>Multiscale Representation</b>	135
5.1	Scale . . . . .	135
5.2	Multigrid Representations . . . . .	138
5.3	<i>Scale Spaces</i> . . . . .	144
5.4	<i>Exercises</i> . . . . .	152
5.5	<i>Further Readings</i> . . . . .	153
<b>II Image Formation and Preprocessing</b>		
<b>6</b>	<b>Quantitative Visualization</b>	157
6.1	Introduction . . . . .	157
6.2	Radiometry, Photometry, Spectroscopy, and Color . . .	159
6.3	<i>Waves and Particles</i> . . . . .	168
6.4	<i>Interactions of Radiation with Matter</i> . . . . .	174
6.5	<i>Exercises</i> . . . . .	186
6.6	<i>Further Readings</i> . . . . .	187
<b>7</b>	<b>Image Formation</b>	189
7.1	Introduction . . . . .	189
7.2	World and Camera Coordinates . . . . .	189
7.3	Ideal Imaging: Perspective Projection . . . . .	192
7.4	Real Imaging . . . . .	195
7.5	Radiometry of Imaging . . . . .	201
7.6	<i>Linear System Theory of Imaging</i> . . . . .	205
7.7	<i>Homogeneous Coordinates</i> . . . . .	212
7.8	<i>Exercises</i> . . . . .	214
7.9	<i>Further Readings</i> . . . . .	215
<b>8</b>	<b>3-D Imaging</b>	217
8.1	Basics . . . . .	217
8.2	<i>Depth from Triangulation</i> . . . . .	221
8.3	<i>Depth from Time-of-Flight</i> . . . . .	228
8.4	<i>Depth from Phase: Interferometry</i> . . . . .	229
8.5	<i>Shape from Shading</i> . . . . .	229
8.6	<i>Depth from Multiple Projections: Tomography</i> . . . . .	235
8.7	<i>Exercises</i> . . . . .	241
8.8	<i>Further Readings</i> . . . . .	242
<b>9</b>	<b>Digitization, Sampling, Quantization</b>	243
9.1	Definition and Effects of Digitization . . . . .	243
9.2	Image Formation, Sampling, Windowing . . . . .	245
9.3	Reconstruction from Samples . . . . .	249
9.4	<i>Multidimensional Sampling on Nonorthogonal Grids</i> . .	251
9.5	<i>Quantization</i> . . . . .	253
9.6	<i>Exercises</i> . . . . .	254

9.7	<i>Further Readings</i> . . . . .	255
<b>10</b>	<b>Pixel Processing</b>	257
10.1	Introduction . . . . .	257
10.2	Homogeneous Point Operations . . . . .	258
10.3	Inhomogeneous Point Operations . . . . .	268
10.4	Geometric Transformations . . . . .	275
10.5	Interpolation . . . . .	279
10.6	<i>Optimized Interpolation</i> . . . . .	286
10.7	<i>Multichannel Point Operations</i> . . . . .	291
10.8	<i>Exercises</i> . . . . .	293
10.9	<i>Further Readings</i> . . . . .	295
<b>III Feature Extraction</b>		
<b>11</b>	<b>Averaging</b>	299
11.1	Introduction . . . . .	299
11.2	General Properties of Averaging Filters . . . . .	299
11.3	Box Filter . . . . .	302
11.4	Binomial Filter . . . . .	306
11.5	Efficient Large-Scale Averaging . . . . .	312
11.6	<i>Nonlinear Averaging</i> . . . . .	321
11.7	<i>Averaging in Multichannel Images</i> . . . . .	326
11.8	<i>Exercises</i> . . . . .	328
11.9	<i>Further Readings</i> . . . . .	330
<b>12</b>	<b>Edges</b>	331
12.1	Introduction . . . . .	331
12.2	Differential Description of Signal Changes . . . . .	332
12.3	General Properties of Edge Filters . . . . .	335
12.4	Gradient-Based Edge Detection . . . . .	338
12.5	Edge Detection by Zero Crossings . . . . .	345
12.6	<i>Optimized Edge Detection</i> . . . . .	347
12.7	<i>Regularized Edge Detection</i> . . . . .	349
12.8	<i>Edges in Multichannel Images</i> . . . . .	353
12.9	<i>Exercises</i> . . . . .	355
12.10	<i>Further Readings</i> . . . . .	357
<b>13</b>	<b>Simple Neighborhoods</b>	359
13.1	Introduction . . . . .	359
13.2	Properties of Simple Neighborhoods . . . . .	360
13.3	First-Order Tensor Representation . . . . .	364
13.4	<i>Local Wave Number and Phase</i> . . . . .	375
13.5	<i>Further Tensor Representations</i> . . . . .	384
13.6	<i>Exercises</i> . . . . .	395
13.7	<i>Further Readings</i> . . . . .	396

<b>14 Motion</b>	397
14.1 Introduction . . . . .	397
14.2 Basics . . . . .	398
14.3 First-Order Differential Methods . . . . .	413
14.4 Tensor Methods . . . . .	418
14.5 Correlation Methods . . . . .	423
14.6 <i>Phase Method</i> . . . . .	426
14.7 <i>Additional Methods</i> . . . . .	428
14.8 <i>Exercises</i> . . . . .	434
14.9 <i>Further Readings</i> . . . . .	434
<b>15 Texture</b>	435
15.1 Introduction . . . . .	435
15.2 First-Order Statistics . . . . .	438
15.3 Rotation and Scale Variant Texture Features . . . . .	442
15.4 <i>Exercises</i> . . . . .	446
15.5 <i>Further Readings</i> . . . . .	446
<b>IV Image Analysis</b>	
<b>16 Segmentation</b>	449
16.1 Introduction . . . . .	449
16.2 Pixel-Based Segmentation . . . . .	449
16.3 Edge-Based Segmentation . . . . .	453
16.4 Region-Based Segmentation . . . . .	454
16.5 Model-Based Segmentation . . . . .	458
16.6 <i>Exercises</i> . . . . .	461
16.7 <i>Further Readings</i> . . . . .	462
<b>17 Regularization and Modeling</b>	463
17.1 Introduction . . . . .	463
17.2 <i>Continuous Modeling I: Variational Approach</i> . . . . .	466
17.3 <i>Continuous Modeling II: Diffusion</i> . . . . .	473
17.4 <i>Discrete Modeling: Inverse Problems</i> . . . . .	478
17.5 <i>Inverse Filtering</i> . . . . .	486
17.6 <i>Further Equivalent Approaches</i> . . . . .	492
17.7 <i>Exercises</i> . . . . .	498
17.8 <i>Further Readings</i> . . . . .	500
<b>18 Morphology</b>	501
18.1 Introduction . . . . .	501
18.2 Neighborhood Operations on Binary Images . . . . .	501
18.3 General Properties . . . . .	503
18.4 Composite Morphological Operators . . . . .	506
18.5 <i>Exercises</i> . . . . .	512
18.6 <i>Further Readings</i> . . . . .	514

<b>19 Shape Presentation and Analysis</b>	515
19.1 Introduction . . . . .	515
19.2 Representation of Shape . . . . .	515
19.3 Moment-Based Shape Features . . . . .	520
19.4 Fourier Descriptors . . . . .	522
19.5 Shape Parameters . . . . .	528
19.6 <i>Exercises</i> . . . . .	531
19.7 <i>Further Readings</i> . . . . .	532
<b>20 Classification</b>	533
20.1 Introduction . . . . .	533
20.2 Feature Space . . . . .	536
20.3 Simple Classification Techniques . . . . .	543
20.4 <i>Exercises</i> . . . . .	548
20.5 <i>Further Readings</i> . . . . .	549
 <b>V Reference Part</b>	
<b>A Reference Material</b>	553
<b>B Notation</b>	577
<b>Bibliography</b>	585
<b>Index</b>	597