

Contents

Preface	xi
Using the book website	xv
1 Representation	1
1.1 What is an image?	1
1.1.1 Image layout	1
1.1.2 Image colour	2
1.2 Resolution and quantization	3
1.2.1 Bit-plane splicing	4
1.3 Image formats	5
1.3.1 Image data types	6
1.3.2 Image compression	7
1.4 Colour spaces	9
1.4.1 RGB	10
1.4.1.1 RGB to grey-scale image conversion	11
1.4.2 Perceptual colour space	12
1.5 Images in Matlab	14
1.5.1 Reading, writing and querying images	14
1.5.2 Basic display of images	15
1.5.3 Accessing pixel values	16
1.5.4 Converting image types	17
Exercises	18
2 Formation	21
2.1 How is an image formed?	21
2.2 The mathematics of image formation	22
2.2.1 Introduction	22
2.2.2 Linear imaging systems	23
2.2.3 Linear superposition integral	24
2.2.4 The Dirac delta or impulse function	25
2.2.5 The point-spread function	28

2.2.6	Linear shift-invariant systems and the convolution integral	29
2.2.7	Convolution: its importance and meaning	30
2.2.8	Multiple convolution: N imaging elements in a linear shift-invariant system	34
2.2.9	Digital convolution	34
2.3	The engineering of image formation	37
2.3.1	The camera	38
2.3.2	The digitization process	40
2.3.2.1	Quantization	40
2.3.2.2	Digitization hardware	42
2.3.2.3	Resolution versus performance	43
2.3.3	Noise	44
	Exercises	46
3	Pixels	49
3.1	What is a pixel?	49
3.2	Operations upon pixels	50
3.2.1	Arithmetic operations on images	51
3.2.1.1	Image addition and subtraction	51
3.2.1.2	Multiplication and division	53
3.2.2	Logical operations on images	54
3.2.3	Thresholding	55
3.3	Point-based operations on images	57
3.3.1	Logarithmic transform	57
3.3.2	Exponential transform	59
3.3.3	Power-law (gamma) transform	61
3.3.3.1	Application: gamma correction	62
3.4	Pixel distributions: histograms	63
3.4.1	Histograms for threshold selection	65
3.4.2	Adaptive thresholding	66
3.4.3	Contrast stretching	67
3.4.4	Histogram equalization	69
3.4.4.1	Histogram equalization theory	69
3.4.4.2	Histogram equalization theory: discrete case	70
3.4.4.3	Histogram equalization in practice	71
3.4.5	Histogram matching	73
3.4.5.1	Histogram-matching theory	73
3.4.5.2	Histogram-matching theory: discrete case	74
3.4.5.3	Histogram matching in practice	75
3.4.6	Adaptive histogram equalization	76
3.4.7	Histogram operations on colour images	79
	Exercises	81

4	Enhancement	85
4.1	Why perform enhancement?	85
4.1.1	Enhancement via image filtering	85
4.2	Pixel neighbourhoods	86
4.3	Filter kernels and the mechanics of linear filtering	87
4.3.1	Nonlinear spatial filtering	90
4.4	Filtering for noise removal	90
4.4.1	Mean filtering	91
4.4.2	Median filtering	92
4.4.3	Rank filtering	94
4.4.4	Gaussian filtering	95
4.5	Filtering for edge detection	97
4.5.1	Derivative filters for discontinuities	97
4.5.2	First-order edge detection	99
4.5.2.1	Linearly separable filtering	101
4.5.3	Second-order edge detection	102
4.5.3.1	Laplacian edge detection	102
4.5.3.2	Laplacian of Gaussian	103
4.5.3.3	Zero-crossing detector	104
4.6	Edge enhancement	105
4.6.1	Laplacian edge sharpening	105
4.6.2	The unsharp mask filter	107
	Exercises	109
5	Fourier transforms and frequency-domain processing	113
5.1	Frequency space: a friendly introduction	113
5.2	Frequency space: the fundamental idea	114
5.2.1	The Fourier series	115
5.3	Calculation of the Fourier spectrum	118
5.4	Complex Fourier series	118
5.5	The 1-D Fourier transform	119
5.6	The inverse Fourier transform and reciprocity	121
5.7	The 2-D Fourier transform	123
5.8	Understanding the Fourier transform: frequency-space filtering	126
5.9	Linear systems and Fourier transforms	129
5.10	The convolution theorem	129
5.11	The optical transfer function	131
5.12	Digital Fourier transforms: the discrete fast Fourier transform	134
5.13	Sampled data: the discrete Fourier transform	135
5.14	The centred discrete Fourier transform	136
6	Image restoration	141
6.1	Imaging models	141
6.2	Nature of the point-spread function and noise	142

6.3	Restoration by the inverse Fourier filter	143
6.4	The Wiener–Helstrom Filter	146
6.5	Origin of the Wiener–Helstrom filter	147
6.6	Acceptable solutions to the imaging equation	151
6.7	Constrained deconvolution	151
6.8	Estimating an unknown point-spread function or optical transfer function	154
6.9	Blind deconvolution	156
6.10	Iterative deconvolution and the Lucy–Richardson algorithm	158
6.11	Matrix formulation of image restoration	161
6.12	The standard least-squares solution	162
6.13	Constrained least-squares restoration	163
6.14	Stochastic input distributions and Bayesian estimators	165
6.15	The generalized Gauss–Markov estimator	165
7	Geometry	169
7.1	The description of shape	169
7.2	Shape-preserving transformations	170
7.3	Shape transformation and homogeneous coordinates	171
7.4	The general 2-D affine transformation	173
7.5	Affine transformation in homogeneous coordinates	174
7.6	The Procrustes transformation	175
7.7	Procrustes alignment	176
7.8	The projective transform	180
7.9	Nonlinear transformations	184
7.10	Warping: the spatial transformation of an image	186
7.11	Overdetermined spatial transformations	189
7.12	The piecewise warp	191
7.13	The piecewise affine warp	191
7.14	Warping: forward and reverse mapping	194
8	Morphological processing	197
8.1	Introduction	197
8.2	Binary images: foreground, background and connectedness	197
8.3	Structuring elements and neighbourhoods	198
8.4	Dilation and erosion	200
8.5	Dilation, erosion and structuring elements within Matlab	201
8.6	Structuring element decomposition and Matlab	202
8.7	Effects and uses of erosion and dilation	204
8.7.1	Application of erosion to particle sizing	207
8.8	Morphological opening and closing	209
8.8.1	The rolling-ball analogy	210
8.9	Boundary extraction	212
8.10	Extracting connected components	213

8.11	Region filling	215
8.12	The hit-or-miss transformation	216
8.12.1	Generalization of hit-or-miss	219
8.13	Relaxing constraints in hit-or-miss: 'don't care' pixels	220
8.13.1	Morphological thinning	222
8.14	Skeletonization	222
8.15	Opening by reconstruction	224
8.16	Grey-scale erosion and dilation	227
8.17	Grey-scale structuring elements: general case	227
8.18	Grey-scale erosion and dilation with flat structuring elements	228
8.19	Grey-scale opening and closing	229
8.20	The top-hat transformation	230
8.21	Summary	231
	Exercises	233
9	Features	235
9.1	Landmarks and shape vectors	235
9.2	Single-parameter shape descriptors	237
9.3	Signatures and the radial Fourier expansion	239
9.4	Statistical moments as region descriptors	243
9.5	Texture features based on statistical measures	246
9.6	Principal component analysis	247
9.7	Principal component analysis: an illustrative example	247
9.8	Theory of principal component analysis: version 1	250
9.9	Theory of principal component analysis: version 2	251
9.10	Principal axes and principal components	253
9.11	Summary of properties of principal component analysis	253
9.12	Dimensionality reduction: the purpose of principal component analysis	256
9.13	Principal components analysis on an ensemble of digital images	257
9.14	Representation of out-of-sample examples using principal component analysis	257
9.15	Key example: eigenfaces and the human face	259
10	Image Segmentation	263
10.1	Image segmentation	263
10.2	Use of image properties and features in segmentation	263
10.3	Intensity thresholding	265
10.3.1	Problems with global thresholding	266
10.4	Region growing and region splitting	267
10.5	Split-and-merge algorithm	267
10.6	The challenge of edge detection	270
10.7	The Laplacian of Gaussian and difference of Gaussians filters	270
10.8	The Canny edge detector	271

10.9	Interest operators	274
10.10	Watershed segmentation	279
10.11	Segmentation functions	280
10.12	Image segmentation with Markov random fields	286
10.12.1	Parameter estimation	288
10.12.2	Neighbourhood weighting parameter θ_n	289
10.12.3	Minimizing $U(x y)$: the iterated conditional modes algorithm	290
11	Classification	291
11.1	The purpose of automated classification	291
11.2	Supervised and unsupervised classification	292
11.3	Classification: a simple example	292
11.4	Design of classification systems	294
11.5	Simple classifiers: prototypes and minimum distance criteria	296
11.6	Linear discriminant functions	297
11.7	Linear discriminant functions in N dimensions	301
11.8	Extension of the minimum distance classifier and the Mahalanobis distance	302
11.9	Bayesian classification: definitions	303
11.10	The Bayes decision rule	304
11.11	The multivariate normal density	306
11.12	Bayesian classifiers for multivariate normal distributions	307
11.12.1	The Fisher linear discriminant	310
11.12.2	Risk and cost functions	311
11.13	Ensemble classifiers	312
11.13.1	Combining weak classifiers: the AdaBoost method	313
11.14	Unsupervised learning: k-means clustering	313
	Further reading	317
	Index	319