Index

Abnormal scans, 312	Bilinear transform, 190
Actual measurement vector, 163	Binary images, 6, 197, 198
AdaBoost method, 313	after thresholding, 238
Adaptive histogram equalization, 76–79	erosion and dilation of, 200
applied to sample image, 79, 80	effects and uses of, 204–205
multi-region calculation approach, 78	to identify features, 206
Adaptive thresholding, 66	Bit-plane slicing, 5, 7
applied to sample image, 66	Bit-plane splicing, 4–5
in Matlab, 66	Blind deconvolution, 156–158
Additive noise, 46	maximum likelihood, 158
Affine transformation, 179	Blurring effect, 85
in homogeneous coordinates, 174–175	Boost filtering. See Unsharp mask filter
property, 175	Boundary extraction, 212–213
Analogue-to-digital (A/D) converter, 41	boundary extraction, 212–213
Anatomical landmarks, 236	Camera, 38–43, 47, 48, 53, 131, 142,
Approximate shape	180, 207
single-parameter measures of, 237	projection models, 38, 39
Automated classification, 293	Canny edge detectors, 102, 271–274
purpose of, 291–292	basic procedure, 272
class labelling, 292	edge direction, 272
task specification, 291–292	hysteresis, 273
task specification, 291–292	·
Racic hitman format (RMD) 6	nonmaximum suppression, 273 use of Gaussian kernel for image, 272
Basic bitmap format (BMP), 6 Basic local texture operators, 245	zero-crossing method, 274
Bayes decision rule, 304–305, 307	practical application of, 273
·	use of LoG and, 273
Bayesian approach, 303, 304	•
Bayesian classifiers, 303, 305	Capture-card-based system, schematic, 42
classification, 310	Capture noise, 44
comparison of, 310	Catchment basins, 279
Bayesian estimators, 165	Class-conditional density function, 305, 307
Bayesian-related reconstruction	Classification systems
techniques, 158	binary classifier, 294
Bayes' law, 286, 287	design of, 294–296
Best linear unbiased estimator	class definition, 294
(BLUE), 167	classifier performance, 295

Classification systems (Continued)	minimize error, 166
data exploration, 294–295	for two variables, 248
descriptions, 296	Cumulative distribution function (CDF), 70, 74
feature selection and extraction, 295	75, 207
flow diagram, 294	
minimum distance criteria, 296–297	2-D affine transformation, 173-174
pattern, 296	Dark-light boundary, 277
prototypes, 296–297	2-D arrays, 6, 7, 9
supervised and unsupervised, 292	3-D arrays, 7, 10
terms, with summary descriptions, 296	2-D cartesian coordinate space
Class prototype, 296	of MxN digital image, 2
Colour slicing, 14	1-D convolution integral, 31
Complex function, 121, 132	Decision boundaries, 298
Compression artefacts, 8, 45	Delta like detector, 32
Computed tomography (CT), 49	Descriptors, rotation-invariant set, 242
Computer peripheral interfaces, 43	Desktop-level multi-processor systems, 44
Computer system, 42, 43, 50	2-D feature space, 292, 293
Connectivity concept, 86	summary statistics for data, 248
Constrained least-squares deconvolution,	weight/height values, distribution
151, 153	of, 247
Constrained least-squares restoration, 163–164	2-D feature vectors, 247, 292
Continuous function, parameters, 95	Difference of Gaussians (DoG), 271
Continuous spatial signal, 1	Digital imaging systems, 34, 40, 161, 247
Contrast stretching, 67–69, 83	noise effects in, 45
applied to sample image, 68	Digital video camera, CCD sensor, 43
Convolution, 30	Digitization process
blind, 157	digitization hardware, 42–43
constrained, 163	quantization, 40–42
of 1-D functions, 29	resolution vs. performance, 43–44
digital, 34–37	3-D imaging, 50
discrete, 35	Dimensionality reduction, 246, 255
with Gaussian blur, 24	Dirac delta function, 25, 26
importance and meaning, 30–34	Discrete Fourier transform (DFT), 135–137, 139
integral, 29	See also Fourier transform
between kernel and image, 88	centring of, 135
kernels, 200	definition of, 136
linear filtering, 88, 95	inverse, 136
multiple, 34	quadrants in, 137
operator, 21	Discrete images, mathematical analysis, 2
with PSF, 22	Discriminant functions, 298, 307
standard, 161	linear, 297–299, 308
theorem, 30, 129–131, 143	in N dimensions, 301
Correspondence, 235, 236, 274	Distortion, 38–40, 44, 169, 184, 185, 190
Cost function, 152	2-D object, 169
least-squares, 177, 178	principal axes of
risk and, 311–312	calculation of, 255
scalar, 163, 164	Domain-specific format, 7
Covariance matrix, 251, 303, 306, 307, 310	2-D projective transformation matrix, 181
diagonalization of, 256	1-D rectangle signal, repeated convolution, 37
	1 2 rectangle digital, repetited convolution, 37

2-D rotation matrix, 156	Filter mask, 95, 100
2-D signal, 49	Finite detector, 33
3-D space, 180	Finite pinhole aperture, 33
	Fisher linear discriminant (FLD)
Edge detection	calculation of, 310
challenges, 270	defining direction within feature space, 311
filtering for (See Image enhancement process)	reducing N-dimensional feature space to, 311
using the zero-crossing method, 274	Floating-point images, 7
Edge-detector kernel, 98	Fourier coefficients, 241, 242
Edge direction. See also Canny edge detector	expansion coefficients, 119, 239
calculation, 272	Fourier descriptors, 241
digitization, 272	Fourier domain, 35, 114, 115, 148
nonmaximum suppression, application, 273	Fourier hypothesis, 119
Edge-spread function (ESF), 155	Fourier transforms, 113, 126–129, 143
EFIT-V, 260	centred discrete, 136–139
Eigenfaces	complex Fourier series, 118–119
and human face, 258–261	convolution theorem, 129–131
linear combination, 260	1-D Fourier transform, 119–121
Eigenvalue spectrum, 259, 260	2-D Fourier transform, 123
Eigenvector/eigenvalue decomposition, 251	central meaning, 125
Eigenvectors R, 253, 254	properties, 124
diagonalizing matrix of, 253	digital Fourier transforms, 134
Ensemble classifiers, 312	Fourier spectrum calculation, 118
automated, 311	frequency space, 113–118
combining weak classifiers, 313	functions, 123
Entropy, 246	inverse Fourier transform/reciprocity,
Error covariance matrix, 166, 167	122–126
Error function, 156	
Euclidean definition, 302	linear systems, 129 optical transfer function, 131–134
•	properties, 124
Euclidean distance, 177, 282, 297, 302	
classifier, 298, 302, 303	sampled data, 135–136
Exponential function, 60, 119	Frequency cut-off, 118
Exponential transform, 59, 60, 82	Frequency domain, 23, 85, 154. See also Fourier
Extracting connected components,	domain
213–215	analysis, 115
D 11	central feature of, 122
Facial prototypes, 297	convolution, 143
Facial recognition, automated, 246	filtering, 127, 128, 130
Facial synthesis, 247	Fourier transform spreading out in, 122
Fast Fourier transform (FFT), 125, 134, 138.	image processing, 126
See also Fourier transform	linear system in, 129
Feature extraction, 97, 169, 263, 292, 295	multiplication of OTFs in, 131
Feature space, 296, 298, 306	restoration, 154
decision boundaries which partition, 298	sampling intervals in, 135
distinct clusters, 293	'standard' deconvolution problem, 154, 156
FLD define direction within, 311	
	Frequency-domain processing, 113
Field programmable gate arrays	centred discrete Fourier transform, 136-139

Frequency-domain processing (Continued)	Grey-scale pixel, 258
1-D Fourier transform, 119–121	Grey-scale sensor, 41
digital Fourier transforms, 134	Grey-scale structuring elements, 227–228
Fourier spectrum calculation, 118	Grey-scale values, 72
Fourier transform, understanding, 126–129	•
frequency space, 113–118	Haralick's criterion, 275
inverse Fourier transform/reciprocity,	Harmonic functions, 23, 114–116, 118, 120, 124, 129
	Harmonic signals, 114
linear systems, 129 optical transfer function, 131–134	Harris function, 276, 277
sampled data, 135–136	Harris response function, 278
Frequency plot, 63	-
	Histogram equalization theory, 69–70
Frequency-space methods, 113, 114	applied to sample image, 73
Common commontion	discrete case, 70–71
Gamma correction	in practice, 71–73
application, 62	Histogram-matching theory, 73–74
based on grey-scale, 83	applied to sample image, 76
power-law transform, 62	discrete case, 74–75
on sample image, 63	in practice, 75–76
Gaussian blur, 24, 145	Histograms, 63–73
Gaussian curves, 288	pixel distributions, 63–64
Gaussian distribution, 288	adaptive thresholding, 66–67
Gaussian filter, 47, 95–97, 109, 110, 158,	contrast stretching, 67–69
270, 277	for threshold selection, 65
Gaussian function, 95, 134, 271, 288	using Otsu's method, 265
Gaussian kernel, 37, 103, 104, 107, 108,	Hit-or-miss transformation, 216–219
272, 273	application to detect target shape, 219
Gaussian noise, 21, 46, 90–95, 97, 109	fully constrained, 220
Gaussian smoothing operator, 104	general form of, 219
Gauss–Markov estimator, 165–167	generalization, 219–220
Geometric construction, for producing skeleton,	to identify locations, 216, 217
223	relaxing constraints in, 220–222
Geometric manipulation of images, 171	steps, to identify points in image,
Gibbs distribution, 287	217, 218
GIF images, 6	Homogeneous coordinates, 171–173
Gradient images	Hue, Saturation and Value (HSV) colour space
preprocessing step in, 280	11–13, 78, 80, 111
watershed, direct calculation of, 282	Human faces
Graphics processing unit (GPU) processing, 44	components of sample of, 257
Grayscale/false colour image, 3	scaled and registered, 259
Grey-scale closing, 229	thumbnail images of, 300
Grey-scale dilation, 227	use of PCA modelling of, 262
with flat structuring elements, 228-229	Human visual system, 3, 41, 42, 97
Grey-scale erosion, 227	
with flat structuring elements, 228-229	Image
Grey-scale image, 11, 12, 63, 69	colour, 2–3
Grey-scale intensity, 49	colour spaces, 9–14
Grey-scale opening, 229	perceptual colour space, 12-14
correction of nonuniform illumination, 230	RGB, 10–12

compression method, 5, 7	key elements, 21
3-D imaging, 50, 180	mathematics of, 22–37
encoding noise, 45	convolution, 30-34
formation (See Image formation process)	digital convolution, 34-37
formats, 5–9	dirac delta/impulse function, 25-27
image compression, 7-9	linear imaging systems, 23-24
image data types, 6-7	linear shift-invariant systems/convolution
properties, 6	integral, 29–30
grey-scale images, 49	linear superposition integral, 24-25
infrared (IR), 49	multiple convolution, 34
layout, 1–2	point-spread function, 28
in Matlab, 14–19	Image histogram, 266. See also Histograms
accessing pixel values, 16-17	Image processing, 264, 265
basic display of images, 15-16	techniques, 87
reading, writing and querying images, 14	Image recognition
medical imaging, 49	colour, 264
neighbourhood connectivity, 86	motion, 264
processing operation, 44, 50 (See also Image	texture, 264
processing)	Image restoration process, 141
radar/sonar imaging, 50	blind deconvolution, 156-158
registration, 179	constrained deconvolution, 151-154
resolution and quantization, 3-5	constrained least-squares restoration,
bit-plane splicing, 4-5	163–164
scientific imaging, 50	generalized Gauss–Markov estimator, 165–167
transformations, 184	imaging equation, solutions to, 151
warping, 186	imaging models, 141-142
Image enhancement process	inverse Fourier filter, restoration by, 143-146
edge detection, filtering for, 97–105	iterative deconvolution, 158-161
derivative filters, for discontinuities, 97–99	Lucy-Richardson algorithm, 158–161
first-order edge detection, 99-101	matrix formulation, 161–162
second-order edge detection, 101-105	point-spread function and noise, nature of,
edge enhancement, 105-109	142–143
Laplacian edge sharpening, 105–107	standard least-squares solution, 162-163
unsharp mask filter, 107–109	stochastic input distributions/Bayesian
filter kernels, 87–90	estimators, 165
goal of, 85	unknown point-spread function/optical
linear filtering mechanics, 87–90	transfer function, 154–156
nonlinear spatial filtering, 90	Wiener-Helstrom filter, 146-147
noise removal, filtering for, 90-97	origin of, 147–151
Gaussian filtering, 95–97	Image segmentation, 170, 263
mean filtering, 91–92	automated methods, 170
median filtering, 93-94	Canny edge detector, 271-274
rank filtering, 94–95	edge/boundary methods, 263
pixel neighbourhoods, 86–87	edge detection, challenge of, 270
via image filtering, 85–86	features, 263–265
Image formation process, 21	image properties, use of, 263–265
engineering of, 37–46	intensity thresholding
camera, 38–44	global thresholding, problems, 266–267
noise, 44–46	using, 265

Image segmentation (Continued)	Laplacian filter, 102
interest operators, 274–279	construction of, 102
Laplacian of a Gaussian (LoG),	Laplacian kernels, 103
270–271	Laplacian of Gaussian (LoG) filter, 103-104,
manual segmentation, 170	270, 274
with Markov random fields	basic shape of, 272
Bayes' theorem, 287	edge sharpening, 106, 107
Gibbs distribution, 287	Law of total probability, 305
iterated conditional modes (ICM)	Linear discriminant, 307
algorithm, 290	functions, 297–301
neighbourhood weighting parameter,	in N dimensions, 301
289–290	Linear functions, 298
parameter estimation, 288-289	Linear imaging system, 23, 28
pixel, 286	action of, 130
noisy, under water image, 289	2-D systems, 141
purpose of, 264	equation, 158
region-based methods, 263	frequency-domain perspective, 129
region growing, 267	main elements, 143
region splitting, 267	Linearly separable filtering, 101
segmentation function, 280–286	Linear machine, 308
split-and-merge algorithm, 267–269	Linear model, 162
watershed segmentation, 279-280	Linear operator, 152
Imaging systems. See Digital imaging systems;	demonstration, 24
Linear imaging system	Linear shift-invariant systems, 29
Impulse function, 25–27	Linear superposition integral, 24
Incident intensity, 33, 34	principle, 25
Intensity quantization effects, 41, 42	Linear transformations
Intensity thresholding, 207, 208, 238, 263,	and effects, 175
265–267, 286	coefficient values, 174
Inverse filter. See Optical transfer function	Line-fit error, 293
(OTF)	Logarithmic function
Isoplanatism. See Shift invariance	parameter, 58
Iterated conditional modes (ICM) algorithm,	Logarithmic transform effect, 58
290	Lossy compression technique, 8, 9
Markov random field segmentation,	LR deconvolution, 161
290	LSI imaging equation, 143, 146
	LSI system, 30
Jet colour map, 3	output of, 34
JPEG format, 6	Lucy–Richardson algorithm,
)120 10111111, 0	158–161
k means algorithm, 313, 314	
k-means clustering, 313–315	Magnetic resonance imaging (MRI), 49
	Mahalanobis distance, 302, 303, 306
Lagrange multipliers method, 164	extension of, 302–303
Landmarks, 235	Mapping function, 59
anatomical/true landmarks, 236	Marker-controlled segmentation,
mathematical landmarks, 236	282, 283
pseudo-landmarks, 236	watershed segmentation, 284
Laplacian edge detection, 101–102	Markov random fields, 286, 287
Lapiacian cuge uciccion, 101-102	iviaikuv taliuulli lielus, 200, 207

Matlab, 1, 3, 14–17, 19, 35, 52, 56, 59, 61, 62, 64,	dilation, 200–201
182, 189, 190, 238–240, 244, 253–255,	to join small breaks in defining
266, 268, 269, 273–274, 277–279,	contour, 205
281–286, 315	erosion, 200–201
adaptive histogram equalization, 78	application in particle sizing, 207-209
contrast stretching in, 68	Morphological processing, 237, 238
convention, 1	Morphological skeletons, 223
filtering effect, 108	Morphological structuring elements, 199
functions, 150	Multivariate normal density, 306
Gaussian filter in, 96	Multivariate normal (MVN) distribution, 305,
histogram matching, 75	307
histogram operations, 80	Bayesian classifiers for, 307-310
HSV implementation, 13	risk and cost functions, 311-312
image multiplication and division, 54	Multivariate normal distributions
image processing toolbox, 158	Bayesian classifiers for
image subtraction, 53	Fisher linear discriminant (FLD),
imfliter() function, 103	310–311
imnoise() function, 47, 91, 109	
linear convolution filtering, 89	N-dimensional space, 251
LoG operator in, 104	N-dimensional vectors, 297
in lossy compression format, 9	Neighbourhood weighting parameter θ_n
LR deconvolution algorithm, 160	289–290
mean filter, 91	Neighbouring pixels, 289
median filtering, 93	Noise, 21, 271
zero-crossing detector with LoG filter,	differential filters
104–105	effect of, 270
Matrix formulation, 161	effects of, 270
Matrix operator, 166	power, 152
Mean filtering, 91	power spectra, 147
drawbacks of, 92	Noise models, 151
Median filtering, 92	nature of, 142–143
Medical imaging, 49–50	Noisy, segmentation of, 289
Mexican hat function, 271	Nonlinear distortion, 184
Minimum distance classifier	Nonlinear transformations, 184-186
extension of, 302-303	degrees of freedom, 184
Minimum mean-square error (MMSE), 148	Normalization. See Contrast stretching
Misclassifications, 300	Normalized central moments possess, 243
relative importance of, 312	Nyquist sampling theorem, 40
Misclassified test, 310	
Modulation transfer function (MTF), 132, 134	Object function, 21
Moore's law, 44	Off-diagonal element, 306
Morphological opening	Opening, by reconstruction, 224–226
and closing, 209–210	Optical transfer function (OTF), 129, 131-134
rolling-ball analogy, 210-212	144, 153
effects of, 224	effect of, 133
Morphological operations, 197	Optimal linear restoration filter, 147
corresponding Matlab® functions, 232	Optimization criterion, 148
to grey-scale and colour images, 198	Orthogonal eigenvectors, 250. See also
Morphological operators, 200	Eigenvectors R

Orthographic projection, 39	Power-law transform, 61, 62
Otsu's method, for threshold selection,	imadjust function, 62
265, 266	Prairie-fire analogy, 222
	Prewitt/Sobel kernels, 100
Periodic square wave synthesis, 117	Principal component analysis (PCA), 235,
Perspective distortion, 38. See also Distortion	246–249
Perspective projection model, effects, 39	basic aim of, 247
Photon-limited system, 29	compact encoding, 260
Picture element, 49	of digital images, 256
Piecewise warp, 191. See also Warping	dimensionality reduction, 255–256
first stage in, 192	for face encoding and recognition, 259
Pin-hole perspective projection model, 39	modelling of human faces, 261
Pixels, 1, 40, 43, 49	out-of-sample data vector, 257
distributions, histograms, 63-73	out-of-sample examples, representation of,
adaptive histogram equalization,	256–258
76–79	pixel-to-pixel basis, 256
adaptive thresholding, 66-67	principal axes, 252
contrast stretching, 67–69	properties of, 252–255
histogram equalization in practice,	real power of, 255
71–73	theory of, 249–252
histogram equalization theory, 69-71	Prior probabilities, 305
histogram matching, 73–76	Probability density function (PDF), 63, 74, 165,
histogram operations on colour images,	207, 243, 305
79–80	Probability theory, 70, 207, 243
for threshold selection, 65	Processing noise, 45
2-D pixel, 3	Procrustes alignment, 170, 176–180
information, type, 51	Procrustes transformation, 175–176
intensity, 72	Projective transformation, 180–184
labelling, analytical approach, 289	coordinate mappings, 183
neighbourhoods, 86–87	defined by mapping, 181
operations upon pixels, 50–57	preserved quantities and, 184
arithmetic operations, 51–54	Pruning, 224
logical operations, 54–55	0
thresholding, 55–57	Quadtree decomposition, 268, 269
point-based operations on images,	Quantization, 3–5
57–63	
exponential transform, 59-61	Radar/sonar imaging, 50
logarithmic transform, 57–59	Radial Fourier expansion, 239–242
power-law (gamma) transform,	Rank filtering, 94–95
61–63	Rdial Fourier expansions, 241
value, types, 86	Rectangle function, 26, 134
PNG format, 6	Fourier transform of, 122
images, 7	Red, green and blue (RGB) image, 7, 10, 12.
Point-spread function (PSF), 21, 22, 131	See also True-colour images
1-D version, 155	colour channels, 17
effect of, 28	colour space, 11
nature of, 142–143	to grey-scale image conversion, 11–12
Poisson density function, 159	values, 79
Poisson noise, 159	Region filling, 215–216

D 1.1 2.5	0 .:16
Resolution, 3–5	Spatial frequency regime, 145
bit resolution, 4	Spatial functions synthesis, 121
spatial resolution, 4	Spatial quantization effects, 41
temporal resolution, 4	Spatial transformation
Roberts, Prewitt and Sobel filters, 100, 101	of image, 186–189
Roberts cross, 99, 100	overdetermined, 189–190
Rolling-ball analogy, 210–212	Split-and-merge algorithm, 267, 268
	Spurs, in skeleton, 224
Salt and pepper noise, 46, 90, 91, 93	Standard least-squares solution, 162-163
Sample covariance matrix, 247	Statistical moments
Sampling noise, 44	over neighbourhood/spatial scale in image,
Sampling theorem, 40	264
Scaling, 178	as region descriptors, 243–245
Scaling constant, 58	Statistical noise distribution, 21
Scaling factor, 39, 57, 108	Structuring element, 198
Scene occlusion, 45	decomposition and Matlab, 202-204
Scientific imaging, 50	function getsequence, 203
Segmentation function, 280–286	functions imdilate and imopen, 204
Segmentation techniques. See Image	strel object, 202–203
segmentation	local neighbourhood defined by, 199
Shannon's sampling theorem, 40	within Matlab, 201–202
Shape, description, 169-170	Sum of squared errors
treatment of boundaries and	principal axis minimizes, 248
shape, 170	Supervised classifiers, 292
Shape descriptors, 169	System matrix, 164, 165
Shape-preserving transformations, 170	
under linear operations of, 171	Texture features, 246
Shape transformation, 171–173	Three-channel RGB images, 54
Shape vector, 169	Thresholding, 55–57
Shift invariance, 29	of complex image, 56
Sifting theorem, 27	for object identification, 56
Signatures, 239–242	variations on, 57
arbitrary scale factor, multiplication	TIFF image format, 7
of, 241	Tile-based approach. See Sliding window
of closed boundary, 239	approach
distance from, 242	Top-hat transformation, 230-231
Simple square-root transform, 59	Translation, 170, 171, 173, 176, 177,
Single-parameter measure, 169	179, 189
Singularity, properties of, 27	invariant, 241, 243
Singular value decomposition (SVD),	parameters, 174
178, 179	vector, 174
Size density function, 208, 209	True-colour images, 7
Skeletonization, 222–224	components, 10
Sliding window approach, 77	
Sobel and Prewitt operators, 100	Unsharp mask filter, 107-109
Sobel operators, 272	edge sharpening, 109
Soft focus effect. See Blurring effect	Unsupervised classifiers
Spatial domain filtering, 85, 86	k-means clustering, 313-315
Spatial-domain image processing, 126	Unsupervised learning algorithms, 313

calculation, 282

Video frame, 4 methods, 280 Voxels, 2 segmentation, 279-280 marker-controlled, 284 Warping, 186 yields, 279, 280 applications, 186 Weak classifier, 313 central concept, 187 Weighting factor, 159 forward and reverse mapping, 194-195 Wiener-Helstrom filter, 146-147 piecewise affine, 191-194 historical importance, 149 piecewise wrap, 191 origin of, 147-151 transformation, basic steps, 188 using global polynomial transformation, 190 Zero-crossing detector, 104 Watershed. See also Image segmentation

Zero-crossing method, 271 edge detection, 274