Index

Abnormal scans, 312 Actual measurement vector, 163 AdaBoost method, 313 Adaptive histogram equalization, 76-79 applied to sample image, 79, 80 multi-region calculation approach, 78 Adaptive thresholding, 66 applied to sample image, 66 in Matlab, 66 Additive noise, 46 Affine transformation, 179 in homogeneous coordinates, 174-175 property, 175 Analogue-to-digital (A/D) converter, 41 Anatomical landmarks, 236 Approximate shape single-parameter measures of, 237 Automated classification, 293 purpose of, 291-292 class labelling, 292 task specification, 291-292

Basic bitmap format (BMP), 6 Basic local texture operators, 245 Bayes decision rule, 304–305, 307 Bayesian approach, 303, 304 Bayesian classifiers, 303, 305 classification, 310 comparison of, 310 Bayesian estimators, 165 Bayesian-related reconstruction techniques, 158 Bayes' law, 286, 287 Best linear unbiased estimator (BLUE), 167 Bilinear transform, 190 Binary images, 6, 197, 198 after thresholding, 238 erosion and dilation of, 200 effects and uses of, 204-205 to identify features, 206 Bit-plane slicing, 5, 7 Bit-plane splicing, 4-5 Blind deconvolution, 156-158 maximum likelihood, 158 Blurring effect, 85 Boost filtering. See Unsharp mask filter Boundary extraction, 212-213 Camera, 38-43, 47, 48, 53, 131, 142, 180, 207 projection models, 38, 39 Canny edge detectors, 102, 271-274 basic procedure, 272 edge direction, 272 hysteresis, 273 nonmaximum suppression, 273 use of Gaussian kernel for image, 272 zero-crossing method, 274 practical application of, 273 use of LoG and, 273 Capture-card-based system, schematic, 42 Capture noise, 44 Catchment basins, 279 Class-conditional density function, 305, 307 Classification systems binary classifier, 294 design of, 294-296 class definition, 294 classifier performance, 295

Fundamentals of Digital Image Processing – A Practical Approach with Examples in Matlab Chris Solomon and Toby Breckon © 2011 John Wiley & Sons, Ltd Classification systems (Continued) data exploration, 294-295 descriptions, 296 feature selection and extraction, 295 flow diagram, 294 minimum distance criteria, 296-297 pattern, 296 prototypes, 296-297 supervised and unsupervised, 292 terms, with summary descriptions, 296 Class prototype, 296 Colour slicing, 14 Complex function, 121, 132 Compression artefacts, 8, 45 Computed tomography (CT), 49 Computer peripheral interfaces, 43 Computer system, 42, 43, 50 Connectivity concept, 86 Constrained least-squares deconvolution, 151, 153 Constrained least-squares restoration, 163-164 Continuous function, parameters, 95 Continuous spatial signal, 1 Contrast stretching, 67-69, 83 applied to sample image, 68 Convolution, 30 blind, 157 constrained, 163 of 1-D functions, 29 digital, 34-37 discrete, 35 with Gaussian blur, 24 importance and meaning, 30-34 integral, 29 between kernel and image, 88 kernels, 200 linear filtering, 88, 95 multiple, 34 operator, 21 with PSF, 22 standard, 161 theorem, 30, 129-131, 143 Correspondence, 235, 236, 274 Cost function, 152 least-squares, 177, 178 risk and, 311-312 scalar, 163, 164 Covariance matrix, 251, 303, 306, 307, 310 diagonalization of, 256

minimize error, 166 for two variables, 248 Cumulative distribution function (CDF), 70, 74, 75.207 2-D affine transformation, 173-174 Dark-light boundary, 277 2-D arrays, 6, 7, 9 3-D arrays, 7, 10 2-D cartesian coordinate space of MxN digital image, 2 1-D convolution integral, 31 Decision boundaries, 298 Delta like detector, 32 Descriptors, rotation-invariant set, 242 Desktop-level multi-processor systems, 44 2-D feature space, 292, 293 summary statistics for data, 248 weight/height values, distribution of, 247 2-D feature vectors, 247, 292 Difference of Gaussians (DoG), 271 Digital imaging systems, 34, 40, 161, 247 noise effects in, 45 Digital video camera, CCD sensor, 43 Digitization process digitization hardware, 42-43 quantization, 40-42 resolution vs. performance, 43-44 3-D imaging, 50 Dimensionality reduction, 246, 255 Dirac delta function, 25, 26 Discrete Fourier transform (DFT), 135-137, 139. See also Fourier transform centring of, 135 definition of, 136 inverse, 136 quadrants in, 137 Discrete images, mathematical analysis, 2 Discriminant functions, 298, 307 linear, 297-299, 308 in N dimensions, 301 Distortion, 38-40, 44, 169, 184, 185, 190 2-D object, 169 principal axes of calculation of, 255 Domain-specific format, 7 2-D projective transformation matrix, 181 1-D rectangle signal, repeated convolution, 37

2-D signal, 49 3-D space, 180 Edge detection challenges, 270 filtering for (See Image enhancement process) using the zero-crossing method, 274 Edge-detector kernel, 98 Edge direction. See also Canny edge detector calculation, 272 digitization, 272 nonmaximum suppression, application, 273 Edge-spread function (ESF), 155 EFIT-V, 260 Eigenfaces and human face, 258-261 linear combination, 260 Eigenvalue spectrum, 259, 260 Eigenvector/eigenvalue decomposition, 251 Eigenvectors R, 253, 254 diagonalizing matrix of, 253 Ensemble classifiers, 312 automated, 311 combining weak classifiers, 313 Entropy, 246 Error covariance matrix, 166, 167 Error function, 156 Euclidean definition, 302 Euclidean distance, 177, 282, 297, 302 classifier, 298, 302, 303 Exponential function, 60, 119 Exponential transform, 59, 60, 82 Extracting connected components, 213-215 Facial prototypes, 297 Facial recognition, automated, 246 Facial synthesis, 247 Fast Fourier transform (FFT), 125, 134, 138. See also Fourier transform Feature extraction, 97, 169, 263, 292, 295 Feature space, 296, 298, 306 decision boundaries which partition, 298 distinct clusters, 293 FLD define direction within, 311 Field programmable gate arrays (FPGA), 44 Filter kernels, 35, 87, 98. See also Filter mask

2-D rotation matrix, 156

Filter mask, 95, 100 Finite detector, 33 Finite pinhole aperture, 33 Fisher linear discriminant (FLD) calculation of, 310 defining direction within feature space, 311 reducing N-dimensional feature space to, 311 Floating-point images, 7 Fourier coefficients, 241, 242 expansion coefficients, 119, 239 Fourier descriptors, 241 Fourier domain, 35, 114, 115, 148 Fourier hypothesis, 119 Fourier transforms, 113, 126-129, 143 centred discrete, 136-139 complex Fourier series, 118-119 convolution theorem, 129-131 1-D Fourier transform, 119-121 2-D Fourier transform, 123 central meaning, 125 properties, 124 digital Fourier transforms, 134 Fourier spectrum calculation, 118 frequency space, 113-118 functions, 123 inverse Fourier transform/reciprocity, 122-126 linear systems, 129 optical transfer function, 131-134 properties, 124 sampled data, 135-136 Frequency cut-off, 118 Frequency domain, 23, 85, 154. See also Fourier domain analysis, 115 central feature of, 122 convolution, 143 filtering, 127, 128, 130 Fourier transform spreading out in, 122 image processing, 126 linear system in, 129 multiplication of OTFs in, 131 restoration, 154 sampling intervals in, 135 'standard' deconvolution problem, 154, 156 Frequency-domain processing, 113 centred discrete Fourier transform, 136-139 complex Fourier series, 118-119 convolution theorem, 129-131

INDEX

Grey-scale pixel, 258

Frequency-domain processing (Continued) 1-D Fourier transform, 119-121 digital Fourier transforms, 134 Fourier spectrum calculation, 118 Fourier transform, understanding, 126-129 frequency space, 113-118 inverse Fourier transform/reciprocity, 122 - 126linear systems, 129 optical transfer function, 131-134 sampled data, 135-136 Frequency plot, 63 Frequency-space methods, 113, 114 Gamma correction application, 62 based on grey-scale, 83 power-law transform, 62 on sample image, 63 Gaussian blur, 24, 145 Gaussian curves, 288 Gaussian distribution, 288 Gaussian filter, 47, 95-97, 109, 110, 158, 270, 277 Gaussian function, 95, 134, 271, 288 Gaussian kernel, 37, 103, 104, 107, 108, 272, 273 Gaussian noise, 21, 46, 90-95, 97, 109 Gaussian smoothing operator, 104 Gauss-Markov estimator, 165-167 Geometric construction, for producing skeleton, 223 Geometric manipulation of images, 171 Gibbs distribution, 287 GIF images, 6 Gradient images preprocessing step in, 280 watershed, direct calculation of, 282 Graphics processing unit (GPU) processing, 44 Grayscale/false colour image, 3 Grey-scale closing, 229 Grey-scale dilation, 227 with flat structuring elements, 228-229 Grey-scale erosion, 227 with flat structuring elements, 228-229 Grey-scale image, 11, 12, 63, 69 Grey-scale intensity, 49 Grey-scale opening, 229 correction of nonuniform illumination, 230

Grey-scale sensor, 41 Grey-scale structuring elements, 227-228 Grey-scale values, 72 Haralick's criterion, 275 Harmonic functions, 23, 114-116, 118, 120, 124, 129 Harmonic signals, 114 Harris function, 276, 277 Harris response function, 278 Histogram equalization theory, 69-70 applied to sample image, 73 discrete case, 70-71 in practice, 71-73 Histogram-matching theory, 73-74 applied to sample image, 76 discrete case, 74-75 in practice, 75-76 Histograms, 63-73 pixel distributions, 63-64 adaptive thresholding, 66-67 contrast stretching, 67-69 for threshold selection, 65 using Otsu's method, 265 Hit-or-miss transformation, 216-219 application to detect target shape, 219 fully constrained, 220 general form of, 219 generalization, 219-220 to identify locations, 216, 217 relaxing constraints in, 220-222 steps, to identify points in image, 217, 218 Homogeneous coordinates, 171-173 Hue, Saturation and Value (HSV) colour space, 11-13, 78, 80, 111 Human faces components of sample of, 257 scaled and registered, 259 thumbnail images of, 300 use of PCA modelling of, 262 Human visual system, 3, 41, 42, 97

Image colour, 2–3 colour spaces, 9–14 perceptual colour space, 12–14 RGB, 10–12

322

INDEX

compression method, 5, 7 3-D imaging, 50, 180 encoding noise, 45 formation (See Image formation process) formats, 5-9 image compression, 7-9 image data types, 6-7 properties, 6 grey-scale images, 49 infrared (IR), 49 layout, 1-2 in Matlab, 14-19 accessing pixel values, 16-17 basic display of images, 15-16 reading, writing and querying images, 14 medical imaging, 49 neighbourhood connectivity, 86 processing operation, 44, 50 (See also Image processing) radar/sonar imaging, 50 registration, 179 resolution and quantization, 3-5 bit-plane splicing, 4-5 scientific imaging, 50 transformations, 184 warping, 186 Image enhancement process edge detection, filtering for, 97-105 derivative filters, for discontinuities, 97-99 first-order edge detection, 99-101 second-order edge detection, 101-105 edge enhancement, 105-109 Laplacian edge sharpening, 105-107 unsharp mask filter, 107-109 filter kernels, 87-90 goal of, 85 linear filtering mechanics, 87-90 nonlinear spatial filtering, 90 noise removal, filtering for, 90-97 Gaussian filtering, 95-97 mean filtering, 91-92 median filtering, 93-94 rank filtering, 94-95 pixel neighbourhoods, 86-87 via image filtering, 85-86 Image formation process, 21 engineering of, 37-46 camera, 38-44 noise, 44-46

key elements, 21 mathematics of, 22-37 convolution, 30-34 digital convolution, 34-37 dirac delta/impulse function, 25-27 linear imaging systems, 23-24 linear shift-invariant systems/convolution integral, 29-30 linear superposition integral, 24-25 multiple convolution, 34 point-spread function, 28 Image histogram, 266. See also Histograms Image processing, 264, 265 techniques, 87 Image recognition colour, 264 motion, 264 texture, 264 Image restoration process, 141 blind deconvolution, 156-158 constrained deconvolution, 151-154 constrained least-squares restoration, 163-164 generalized Gauss-Markov estimator, 165-167 imaging equation, solutions to, 151 imaging models, 141-142 inverse Fourier filter, restoration by, 143-146 iterative deconvolution, 158-161 Lucy-Richardson algorithm, 158-161 matrix formulation, 161-162 point-spread function and noise, nature of, 142-143 standard least-squares solution, 162-163 stochastic input distributions/Bayesian estimators, 165 unknown point-spread function/optical transfer function, 154-156 Wiener-Helstrom filter, 146-147 origin of, 147-151 Image segmentation, 170, 263 automated methods, 170 Canny edge detector, 271-274 edge/boundary methods, 263 edge detection, challenge of, 270 features, 263-265 image properties, use of, 263-265 intensity thresholding global thresholding, problems, 266-267 using, 265

Image segmentation (Continued) interest operators, 274-279 Laplacian of a Gaussian (LoG), 270-271 manual segmentation, 170 with Markov random fields Bayes' theorem, 287 Gibbs distribution, 287 iterated conditional modes (ICM) algorithm, 290 neighbourhood weighting parameter, 289-290 parameter estimation, 288-289 pixel, 286 noisy, under water image, 289 purpose of, 264 region-based methods, 263 region growing, 267 region splitting, 267 segmentation function, 280-286 split-and-merge algorithm, 267-269 watershed segmentation, 279-280 Imaging systems. See Digital imaging systems; Linear imaging system Impulse function, 25-27 Incident intensity, 33, 34 Intensity quantization effects, 41, 42 Intensity thresholding, 207, 208, 238, 263, 265-267, 286 Inverse filter. See Optical transfer function (OTF) Isoplanatism. See Shift invariance Iterated conditional modes (ICM) algorithm, 290 Markov random field segmentation, 290 Jet colour map, 3 JPEG format, 6 k means algorithm, 313, 314 k-means clustering, 313-315 Lagrange multipliers method, 164 Landmarks, 235 anatomical/true landmarks, 236

mathematical landmarks, 236 pseudo-landmarks, 236 Laplacian edge detection, 101–102

Laplacian filter, 102 construction of, 102 Laplacian kernels, 103 Laplacian of Gaussian (LoG) filter, 103-104, 270, 274 basic shape of, 272 edge sharpening, 106, 107 Law of total probability, 305 Linear discriminant, 307 functions, 297-301 in N dimensions, 301 Linear functions, 298 Linear imaging system, 23, 28 action of, 130 2-D systems, 141 equation, 158 frequency-domain perspective, 129 main elements, 143 Linearly separable filtering, 101 Linear machine, 308 Linear model, 162 Linear operator, 152 demonstration, 24 Linear shift-invariant systems, 29 Linear superposition integral, 24 principle, 25 Linear transformations and effects, 175 coefficient values, 174 Line-fit error, 293 Logarithmic function parameter, 58 Logarithmic transform effect, 58 Lossy compression technique, 8, 9 LR deconvolution, 161 LSI imaging equation, 143, 146 LSI system, 30 output of, 34 Lucy-Richardson algorithm, 158 - 161

Magnetic resonance imaging (MRI), 49 Mahalanobis distance, 302, 303, 306 extension of, 302–303 Mapping function, 59 Marker-controlled segmentation, 282, 283 watershed segmentation, 284 Markov random fields, 286, 287 Matlab, 1, 3, 14-17, 19, 35, 52, 56, 59, 61, 62, 64, 182, 189, 190, 238-240, 244, 253-255, 266, 268, 269, 273-274, 277-279, 281-286, 315 adaptive histogram equalization, 78 contrast stretching in, 68 convention, 1 filtering effect, 108 functions, 150 Gaussian filter in, 96 histogram matching, 75 histogram operations, 80 HSV implementation, 13 image multiplication and division, 54 image processing toolbox, 158 image subtraction, 53 imfliter() function, 103 imnoise() function, 47, 91, 109 linear convolution filtering, 89 LoG operator in, 104 in lossy compression format, 9 LR deconvolution algorithm, 160 mean filter, 91 median filtering, 93 zero-crossing detector with LoG filter, 104-105 Matrix formulation, 161 Matrix operator, 166 Mean filtering, 91 drawbacks of, 92 Median filtering, 92 Medical imaging, 49-50 Mexican hat function, 271 Minimum distance classifier extension of, 302-303 Minimum mean-square error (MMSE), 148 Misclassifications, 300 relative importance of, 312 Misclassified test, 310 Modulation transfer function (MTF), 132, 134 Moore's law, 44 Morphological opening and closing, 209-210 rolling-ball analogy, 210–212 effects of, 224 Morphological operations, 197 corresponding Matlab® functions, 232 to grey-scale and colour images, 198 Morphological operators, 200

dilation, 200-201 to join small breaks in defining contour, 205 erosion, 200-201 application in particle sizing, 207-209 Morphological processing, 237, 238 Morphological skeletons, 223 Morphological structuring elements, 199 Multivariate normal density, 306 Multivariate normal (MVN) distribution, 305, 307 Bayesian classifiers for, 307-310 risk and cost functions, 311-312 Multivariate normal distributions Bayesian classifiers for Fisher linear discriminant (FLD), 310-311 N-dimensional space, 251 N-dimensional vectors, 297 Neighbourhood weighting parameter θ_n 289-290 Neighbouring pixels, 289 Noise, 21, 271 differential filters effect of, 270 effects of, 270 power, 152 power spectra, 147 Noise models, 151 nature of, 142-143 Noisy, segmentation of, 289 Nonlinear distortion, 184 Nonlinear transformations, 184–186 degrees of freedom, 184 Normalization. See Contrast stretching Normalized central moments possess, 243 Nyquist sampling theorem, 40 Object function, 21 Off-diagonal element, 306 Opening, by reconstruction, 224–226 Optical transfer function (OTF), 129, 131-134, 144, 153 effect of, 133 Optimal linear restoration filter, 147 Optimization criterion, 148

Orthogonal eigenvectors, 250. See also Eigenvectors R Orthographic projection, 39 Otsu's method, for threshold selection, 265, 266 Periodic square wave synthesis, 117 Perspective distortion, 38. See also Distortion Perspective projection model, effects, 39 Photon-limited system, 29 Picture element, 49 Piecewise warp, 191. See also Warping first stage in, 192 Pin-hole perspective projection model, 39 Pixels, 1, 40, 43, 49 distributions, histograms, 63-73 adaptive histogram equalization, 76-79 adaptive thresholding, 66-67 contrast stretching, 67-69 histogram equalization in practice, 71-73 histogram equalization theory, 69-71 histogram matching, 73-76 histogram operations on colour images, 79-80 for threshold selection, 65 2-D pixel, 3 information, type, 51 intensity, 72 labelling, analytical approach, 289 neighbourhoods, 86-87 operations upon pixels, 50-57 arithmetic operations, 51-54 logical operations, 54-55 thresholding, 55-57 point-based operations on images, 57-63 exponential transform, 59-61 logarithmic transform, 57-59 power-law (gamma) transform, 61-63 value, types, 86 PNG format, 6 images, 7 Point-spread function (PSF), 21, 22, 131 1-D version, 155 effect of, 28 nature of, 142-143 Poisson density function, 159 Poisson noise, 159

Power-law transform, 61, 62 imadjust function, 62 Prairie-fire analogy, 222 Prewitt/Sobel kernels, 100 Principal component analysis (PCA), 235, 246-249 basic aim of, 247 compact encoding, 260 of digital images, 256 dimensionality reduction, 255-256 for face encoding and recognition, 259 modelling of human faces, 261 out-of-sample data vector, 257 out-of-sample examples, representation of, 256-258 pixel-to-pixel basis, 256 principal axes, 252 properties of, 252-255 real power of, 255 theory of, 249-252 Prior probabilities, 305 Probability density function (PDF), 63, 74, 165, 207, 243, 305 Probability theory, 70, 207, 243 Processing noise, 45 Procrustes alignment, 170, 176-180 Procrustes transformation, 175-176 Projective transformation, 180-184 coordinate mappings, 183 defined by mapping, 181 preserved quantities and, 184 Pruning, 224 Quadtree decomposition, 268, 269 Quantization, 3-5 Radar/sonar imaging, 50 Radial Fourier expansion, 239-242 Rank filtering, 94-95 Rdial Fourier expansions, 241 Rectangle function, 26, 134 Fourier transform of, 122 Red, green and blue (RGB) image, 7, 10, 12.

Red, green and blue (RGB) image, 7, 10, 1 See also True-colour images colour channels, 17 colour space, 11 to grey-scale image conversion, 11–12 values, 79 Region filling, 215–216

Resolution, 3-5 bit resolution, 4 spatial resolution, 4 temporal resolution, 4 Roberts, Prewitt and Sobel filters, 100, 101 Roberts cross, 99, 100 Rolling-ball analogy, 210-212 Salt and pepper noise, 46, 90, 91, 93 Sample covariance matrix, 247 Sampling noise, 44 Sampling theorem, 40 Scaling, 178 Scaling constant, 58 Scaling factor, 39, 57, 108 Scene occlusion, 45 Scientific imaging, 50 Segmentation function, 280-286 Segmentation techniques. See Image segmentation Shannon's sampling theorem, 40 Shape, description, 169-170 treatment of boundaries and shape, 170 Shape descriptors, 169 Shape-preserving transformations, 170 under linear operations of, 171 Shape transformation, 171-173 Shape vector, 169 Shift invariance, 29 Sifting theorem, 27 Signatures, 239-242 arbitrary scale factor, multiplication of, 241 of closed boundary, 239 distance from, 242 Simple square-root transform, 59 Single-parameter measure, 169 Singularity, properties of, 27 Singular value decomposition (SVD), 178, 179 Size density function, 208, 209 Skeletonization, 222-224 Sliding window approach, 77 Sobel and Prewitt operators, 100 Sobel operators, 272 Soft focus effect. See Blurring effect Spatial domain filtering, 85, 86 Spatial-domain image processing, 126

Spatial frequency regime, 145 Spatial functions synthesis, 121 Spatial quantization effects, 41 Spatial transformation of image, 186-189 overdetermined, 189-190 Split-and-merge algorithm, 267, 268 Spurs, in skeleton, 224 Standard least-squares solution, 162-163 Statistical moments over neighbourhood/spatial scale in image, 264 as region descriptors, 243-245 Statistical noise distribution, 21 Structuring element, 198 decomposition and Matlab, 202-204 function getsequence, 203 functions imdilate and imopen, 204 strel object, 202-203 local neighbourhood defined by, 199 within Matlab, 201-202 Sum of squared errors principal axis minimizes, 248 Supervised classifiers, 292 System matrix, 164, 165 Texture features, 246

Three-channel RGB images, 54 Thresholding, 55-57 of complex image, 56 for object identification, 56 variations on, 57 TIFF image format, 7 Tile-based approach. See Sliding window approach Top-hat transformation, 230-231 Translation, 170, 171, 173, 176, 177, 179, 189 invariant, 241, 243 parameters, 174 vector, 174 True-colour images, 7 components, 10

Unsharp mask filter, 107–109 edge sharpening, 109 Unsupervised classifiers k-means clustering, 313–315 Unsupervised learning algorithms, 313

INDEX

Video frame, 4 Voxels, 2

Warping, 186 applications, 186 central concept, 187 forward and reverse mapping, 194–195 piecewise affine, 191–194 piecewise wrap, 191 transformation, basic steps, 188 using global polynomial transformation, 190 Watershed. *See also* Image segmentation calculation, 282 methods, 280 segmentation, 279–280 marker-controlled, 284 yields, 279, 280 Weak classifier, 313 Weighting factor, 159 Wiener–Helstrom filter, 146–147 historical importance, 149 origin of, 147–151

Zero-crossing detector, 104 Zero-crossing method, 271 edge detection, 274

328