

Table of Contents

| | |
|--|----|
| 1. Introduction to Applications and Methods | 1 |
| 1.1 Introduction | 1 |
| 1.2 Transformation and Data Representation | 3 |
| 1.2.1 Fourier Analysis | 5 |
| 1.2.2 Time-Frequency Representation | 6 |
| 1.2.3 Time-Scale Representation: The Wavelet Transform | 9 |
| 1.2.4 The Radon Transform | 12 |
| 1.2.5 The Ridgelet Transform | 12 |
| 1.2.6 The Curvelet Transform | 14 |
| 1.3 Mathematical Morphology | 15 |
| 1.4 Edge Detection | 18 |
| 1.4.1 First Order Derivative Edge Detection | 18 |
| 1.4.2 Second Order Derivative Edge Detection | 20 |
| 1.5 Segmentation | 23 |
| 1.6 Pattern Recognition | 24 |
| 1.7 Chapter Summary | 27 |
| 2. Filtering | 29 |
| 2.1 Introduction | 29 |
| 2.2 Multiscale Transforms | 31 |
| 2.2.1 The A Trouis Isotropic Wavelet Transform | 31 |
| 2.2.2 Multiscale Transforms Compared to Other Data Transforms | 33 |
| 2.2.3 Choice of Multiscale Transform | 36 |
| 2.2.4 The Multiresolution Support | 37 |
| 2.3 Significant Wavelet Coefficients | 38 |
| 2.3.1 Definition | 38 |
| 2.3.2 Noise Modeling | 39 |
| 2.3.3 Automatic Estimation of Gaussian Noise | 40 |
| 2.3.4 Detection Level Using the FDR | 48 |
| 2.4 Filtering and Wavelet Coefficient Thresholding | 50 |
| 2.4.1 Thresholding | 50 |
| 2.4.2 Iterative Filtering | 51 |
| 2.4.3 Other Wavelet Denoising Methods | 52 |

| | | | | | |
|-------|--|-----|-------|--|-----|
| 2.4.4 | Experiments | 54 | 4. | Detection | 111 |
| 2.4.5 | Iterative Filtering with a Smoothness Constraint | 56 | 4.1 | Introduction | 111 |
| 2.5 | Filtering from the Curvelet Transform | 57 | 4.2 | From Images to Catalogs | 112 |
| 2.5.1 | Contrast Enhancement | 57 | 4.3 | Multiscale Vision Model | 116 |
| 2.5.2 | Curvelet Denoising | 59 | 4.3.1 | Introduction | 116 |
| 2.5.3 | The Combined Filtering Method | 61 | 4.3.2 | Multiscale Vision Model Definition | 117 |
| 2.6 | Haar Wavelet Transform and Poisson Noise | 63 | 4.3.3 | From Wavelet Coefficients to Object Identification | 117 |
| 2.6.1 | Haar Wavelet Transform | 63 | 4.3.4 | Partial Reconstruction | 120 |
| 2.6.2 | Poisson Noise and Haar Wavelet Coefficients | 64 | 4.3.5 | Examples | 122 |
| 2.6.3 | Experiments | 67 | 4.3.6 | Application to ISOCAM Data Calibration | 122 |
| 2.7 | Chapter Summary | 70 | 4.4 | Detection and Deconvolution | 126 |
| 3. | Deconvolution | 71 | 4.5 | Detection in the Cosmological Microwave Background | 130 |
| 3.1 | Introduction | 71 | 4.5.1 | Introduction | 130 |
| 3.2 | The Deconvolution Problem | 74 | 4.5.2 | Point Sources on a Gaussian Background | 132 |
| 3.3 | Linear Regularized Methods | 75 | 4.5.3 | Non-Gaussianity | 132 |
| 3.3.1 | Least Squares Solution | 75 | 4.6 | Conclusion | 135 |
| 3.3.2 | Tikhonov Regularization | 75 | 4.7 | Chapter Summary | 135 |
| 3.3.3 | Generalization | 76 | 5. | Image Compression | 137 |
| 3.4 | CLEAN | 78 | 5.1 | Introduction | 137 |
| 3.5 | Bayesian Methodology | 78 | 5.2 | Lossy Image Compression Methods | 139 |
| 3.5.1 | Definition | 78 | 5.2.1 | The Principle | 139 |
| 3.5.2 | Maximum Likelihood with Gaussian Noise | 79 | 5.2.2 | Compression with Pyramidal Median Transform | 140 |
| 3.5.3 | Gaussian Bayes Model | 79 | 5.2.3 | PMT and Image Compression | 142 |
| 3.5.4 | Maximum Likelihood with Poisson Noise | 80 | 5.2.4 | Compression Packages | 145 |
| 3.5.5 | Poisson Bayes Model | 81 | 5.2.5 | Remarks on these Methods | 146 |
| 3.5.6 | Maximum Entropy Method | 81 | 5.2.6 | Other Lossy Compression Methods | 148 |
| 3.5.7 | Other Regularization Models | 82 | 5.3 | Comparison | 149 |
| 3.6 | Iterative Regularized Methods | 84 | 5.3.1 | Quality Assessment | 149 |
| 3.6.1 | Constraints | 84 | 5.3.2 | Visual Quality | 150 |
| 3.6.2 | Jansson-Van Cittert Method | 85 | 5.3.3 | First Aladin Project Study | 151 |
| 3.6.3 | Other Iterative Methods | 85 | 5.3.4 | Second Aladin Project Study | 155 |
| 3.7 | Wavelet-Based Deconvolution | 86 | 5.3.5 | Computation Time | 159 |
| 3.7.1 | Introduction | 86 | 5.3.6 | Conclusion | 160 |
| 3.7.2 | Wavelet-Vaguelette Decomposition | 87 | 5.4 | Lossless Image Compression | 161 |
| 3.7.3 | Regularization from the Multiresolution Support | 90 | 5.4.1 | Introduction | 161 |
| 3.7.4 | Wavelet CLEAN | 93 | 5.4.2 | The Lifting Scheme | 161 |
| 3.7.5 | The Wavelet Constraint | 98 | 5.4.3 | Comparison | 166 |
| 3.8 | Deconvolution and Resolution | 104 | 5.5 | Large Images: Compression and Visualization | 167 |
| 3.9 | Super-Resolution | 105 | 5.5.1 | Large Image Visualization Environment: LIVE | 167 |
| 3.9.1 | Definition | 105 | 5.5.2 | Decompression by Scale and by Region | 168 |
| 3.9.2 | Gerchberg-Saxon Papoulis Method | 106 | 5.5.3 | The SAO-DS9 LIVE Implementation | 169 |
| 3.9.3 | Deconvolution with Interpolation | 107 | 5.6 | Hyperspectral Compression for Planetary Space Missions | 170 |
| 3.9.4 | Undersampled Point Spread Function | 107 | 5.7 | Chapter Summary | 173 |
| 3.10 | Conclusions and Chapter Summary | 109 | | | |

| | | | |
|--|-----|--|-----|
| 6. Multichannel Data | 175 | 7.6 Multichannel Data Filtering | 225 |
| 6.1 Introduction | 175 | 7.7 Relevant Information in an Image | 228 |
| 6.2 The Wavelet-Karhunen-Loève Transform | 176 | 7.8 Multiscale Entropy and Optimal Compressibility | 230 |
| 6.2.1 Definition | 176 | 7.9 Conclusions and Chapter Summary | 231 |
| 6.2.2 Correlation Matrix and Noise Modeling | 178 | 8. Astronomical Catalog Analysis | 233 |
| 6.2.3 Scale and Karhunen-Loève Transform | 179 | 8.1 Introduction | 233 |
| 6.2.4 The WT-KLT Transform | 179 | 8.2 Two-Point Correlation Function | 234 |
| 6.2.5 The WT-KLT Reconstruction Algorithm | 180 | 8.2.1 Introduction | 234 |
| 6.3 Noise Modeling in the WT-KLT Space | 180 | 8.2.2 Determining the 2-Point Correlation Function | 235 |
| 6.4 Multichannel Data Filtering | 181 | 8.2.3 Error Analysis | 236 |
| 6.4.1 Introduction | 181 | 8.2.4 Correlation Length Determination | 237 |
| 6.4.2 Reconstruction from a Subset of Eigenvectors | 181 | 8.2.5 Creation of Random Catalogs | 237 |
| 6.4.3 WT-KLT Coefficient Thresholding | 183 | 8.2.6 Examples | 238 |
| 6.4.4 Example: Astronomical Source Detection | 183 | 8.2.7 Limitation of the Two-Point Correlation Function: Toward Higher Moments | 242 |
| 6.5 The Haar-Multichannel Transform | 183 | 8.3 The Genus Curve | 245 |
| 6.6 Independent Component Analysis | 184 | 8.4 Minkowski Functionals | 247 |
| 6.6.1 Definition | 184 | 8.5 Fractal Analysis | 249 |
| 6.6.2 JADE | 185 | 8.5.1 Introduction | 249 |
| 6.6.3 FastICA | 186 | 8.5.2 The Hausdorff and Minkowski Measures | 250 |
| 6.7 CMB Data and the SMICA ICA Method | 189 | 8.5.3 The Hausdorff and Minkowski Dimensions | 251 |
| 6.7.1 The CMB Mixture Problem | 189 | 8.5.4 Multifractality | 251 |
| 6.7.2 SMICA | 190 | 8.5.5 Generalized Fractal Dimension | 253 |
| 6.8 ICA and Wavelets | 193 | 8.5.6 Wavelets and Multifractality | 253 |
| 6.8.1 WJADE | 193 | 8.6 Spanning Trees and Graph Clustering | 257 |
| 6.8.2 Covariance Matching in Wavelet Space: WSMICA | 194 | 8.7 Voronoi Tessellation and Percolation | 259 |
| 6.8.3 Numerical Experiments | 195 | 8.8 Model-Based Clustering | 260 |
| 6.9 Chapter Summary | 198 | 8.8.1 Modeling of Signal and Noise | 260 |
| 7. An Entropic Tour of Astronomical Data Analysis | 201 | 8.8.2 Application to Thresholding | 262 |
| 7.1 Introduction | 201 | 8.9 Wavelet Analysis | 263 |
| 7.2 The Concept of Entropy | 204 | 8.10 Nearest Neighbor Clutter Removal | 265 |
| 7.3 Multiscale Entropy | 210 | 8.11 Chapter Summary | 266 |
| 7.3.1 Definition | 210 | 9. Multiple Resolution in Data Storage and Retrieval | 267 |
| 7.3.2 Signal and Noise Information | 212 | 9.1 Introduction | 267 |
| 7.4 Multiscale Entropy Filtering | 215 | 9.2 Wavelets in Database Management | 267 |
| 7.4.1 Filtering | 215 | 9.3 Fast Cluster Analysis | 269 |
| 7.4.2 The Regularization Parameter | 215 | 9.4 Nearest Neighbor Finding on Graphs | 271 |
| 7.4.3 Use of a Model | 217 | 9.5 Cluster-Based User Interfaces | 272 |
| 7.4.4 The Multiscale Entropy Filtering Algorithm | 218 | 9.6 Images from Data | 273 |
| 7.4.5 Optimization | 219 | 9.6.1 Matrix Sequencing | 273 |
| 7.4.6 Examples | 220 | 9.6.2 Filtering Hypertext | 277 |
| 7.5 Deconvolution | 220 | 9.6.3 Clustering Document-Term Data | 278 |
| 7.5.1 The Principle | 220 | 9.7 Chapter Summary | 282 |
| 7.5.2 The Parameters | 224 | | |
| 7.5.3 Examples | 225 | | |

| | |
|---|-----|
| 10. Towards the Virtual Observatory | 285 |
| 10.1 Data and Information | 285 |
| 10.2 The Information Handling Challenges Facing Us..... | 287 |

Appendix

| | |
|--|-----|
| A. A Trous Wavelet Transform | 291 |
| B. Picard Iteration | 297 |
| C. Wavelet Transform Using the Fourier Transform | 299 |
| D. Derivative Needed for the Minimization | 303 |
| E. Generalization of the Derivative Needed for the Minimization | 307 |
| F. Software and Related Developments | 309 |
| Bibliography | 311 |
| Index | 331 |