Contents

Streszczenie 9

Summary 11

Notations and abbreviations 13

1. Introduction 17

2. Tensor methods in computer vision 21

2.1. Introduction 21
2.2. Tensor – a mathematical object 22
2.2.1. Main properties of linear spaces 23
2.2.2. Concept of a tensor 23
2.2.3. Basic properties of tensors 25
2.3. Tensor – a data object 26
2.4. Derivation of the structural tensor 27
2.4.1. Structural tensor in two-dimensional space 29
2.4.2. Structural tensor in higher-dimensions 31
2.4.3. Multi-channel and scale-space structural tensor 33
2.4.4. Extended structural tensor 35
2.5. Tensor-driven diffusion 35
2.6. Object representation with tensor of inertia 37
2.7. Eigen-decomposition and representation of tensors 39
2.8. Tensor invariants 43
2.9. Filtering of tensor fields 44
2.9.1. Order statistic filtering of tensor data 44
2.10. Multi-focal tensors 47
2.11. Multilinear tensor methods 50
2.11.1. Basic concepts of the multilinear algebra 52
2.11.2. Higher-order singular value decomposition 59
2.11.3. Computation of the HOSVD 61
2.11.4. Best rank-one and rank-(R_1, R_2, …, R_P) approximations 64
2.11.5. Factorization of nonnegative tensors 66
2.11.6. Multilinear image processing 67

3. Classification methods and algorithms 69

3.1. Introduction 69
3.2. Statistical formulation of the object recognition 69
3.2.1. Parametric and nonparametric methods 69
3.2.2. Maximum likelihood recognition 70
3.2.3. Bayes framework 71
3.2.4. Maximum a posteriori classification scheme 71
3.2.5. Binary classification problem 72
3.3. Parametric methods – mixture of Gaussians 73
3.4. Non-parametric methods 78
3.4.1. Histogram based techniques 78
3.4.2. Parzen method 84
3.4.2.1. Kernel based methods 85
3.4.2.2. Nearest-neighbor method 87
3.5. Probabilistic neural network 88
3.6. Hamming neural network 89
3.7. Morphological neural network 92
3.8. The mean shift method 95
3.8.1. Method specification 95
3.8.2. Continuously adaptive mean shift method 100
3.8.3. Algorithmic aspects of the mean shift tracking 102
3.8.3.1. Tracking of multiple features 102
3.8.3.2. Tracking of multiple objects 103
3.8.3.3. Fuzzy approach to the *CamShift* 104
3.8.3.4. Discrimination with background information 104
3.8.3.5. Adaptive update of the classifiers 105
3.9. Support vector domain description 106
3.9.1. Kernels for object classification 111

4. Detection and tracking 114

4.1. Introduction 114
4.2. Direct pixel classification 114
4.2.1. CASE STUDY – Human skin detection 115
4.2.2. CASE STUDY – Pixel based road signs detection 119
4.2.2.1. Fuzzy approach 119
4.2.2.2. SVM based approach 123
4.3. Detection of basic shapes 127
4.3.1. Detection of line segments 129
4.3.2. Up-Write detection of convex shapes 130
4.4. Figure Detection 132
4.4.1. Detection of regular shapes from salient points 133
4.4.2. Clusterization of the salient points 136
4.4.3. The adaptive window growing method 137
4.4.4. Figure verification 138
4.4.5. CASE STUDY – Road signs detection system 140

4.5. Object tracking 146
4.5.1. CASE STUDY – Road signs tracking and classification 146
4.5.2. CASE STUDY – General framework for object tracking 150

5. Recognition 157

5.1. Introduction 157
5.2. Recognition from tensor phase histograms and morphological scale 157
5.2.1. Computation of the phase histograms in MSS 159
5.2.2. Matching of the phase histograms 161
5.2.3. CASE STUDY – Recognition of real objects with tensor histograms 163
5.3. Template matching 169
5.4. Recognition in the log-polar and Gaussian scale spaces 173
5.5. Invariant based recognition 178
5.5.1. CASE STUDY – Pictogram recognition with affine moment invariants 178
5.6. Recognition in the domain of deformable models 182
5.6.1. CASE STUDY – Road signs recognition with deformable models 183
5.7. Ensembles of classifiers 188
5.7.1. CASE STUDY – Mixture of expert classifiers for signs recognition 191
5.7.2. The arbitration unit 193
5.8. Computer vision systems 193
5.8.1. CASE STUDY – Road signs recognition system 194
5.8.1.1. Problem analysis 195
5.8.1.2. Architecture of the system 196
5.8.1.3. Activity of the system 196

6. Closure 199

7. Appendix 201

7.1. Morphological scale-space 201
7.2. Morphological tensor operators 203
7.3. Geometry of quadratic forms 204
7.4. Testing classifiers 205

References 209

Index 223