Table of Contents

Dedication xiii

Preface xv

Author Biography xvii

### **1** Concepts and Foundations Automation and Emerging Technologies **1**

- 1.1 Introduction 1
- 1.2 Structure and Framework of Automation and Key Performance Indexes (KPIs) 3
- 1.3 Advanced Image Processing Techniques 4
- 1.4 Fuzzy and Its Recent Advances 6
- 1.5 Automatic Detection and Its Applications in Infrastructure 6
- 1.6 Feature Extraction and Fragmentation Methods 8
- 1.7 Feature Prioritization and Selection Methods 8
- 1.8 Classification Methods and Its Applications in Infrastructure Management 10
- 1.9 Models of Performance Measures and Quantification in Automation 11
- 1.10 Nature-Inspired Optimization Algorithms (NIOAS) 12
- 1.11 Summary and Conclusion 14
- 1.12 Questions and Exercise 14

#### 2 The Structure and Framework of Automation and Key Performance Indices (KPIs) 15

- 2.1 Introduction 15
- 2.2 Macro Plan and Architecture of Automation 16
- 2.2.1 Infrastructure Automation 16
- 2.2.2 Importance of Infrastructure Automation Evaluation 16
- 2.3 A General Framework and Design of Automation 17

2.4 Infrastructure Condition Index and Its Relationship with Cracking 20

- 2.4.1 Road Condition Index 20
- 2.4.2 Bridge Condition Index 28
- 2.4.3 Tunnel Condition Index 31
- 2.5 Automation, Emerging Technologies, and Futures Studies 31
- 2.6 Summary and Conclusion 32
- 2.7 Questions 32
- Further Reading 32

## 3 Advanced Images Processing Techniques 35

Introduction 35

- 3.1 Preprocessing (PPS) 36
- 3.1.1 Edge Preservation Index (EPI) 39
- 3.1.2 Edge-Strength Similarity-Based Image Quality Metric (ESSIM) 39
- 3.1.3 QILV Index 40
- 3.1.4 Structural Content Index (SCI) 40
- 3.1.5 Signal-To-Noise Ratio Index (PSNR) 41
- 3.1.6 Computational time index (CTI) 41
- 3.2 Preprocessing Using Single-Level Methods 41
- 3.2.1 Single-Level Methods 42
- 3.2.2 Linear Location Filter (LLF) 42
- 3.2.3 Median Filter 44
- 3.2.4 Wiener Filter 45
- 3.3 Preprocessing Using Multilevel (Multiresolution) Methods 49

3.3.1 Wavelet Method 49

- 3.3.2 Ridgelet Transform 57
- 3.3.3 Curvelet Transform 62
- 3.3.4 Decompaction and Reconstruction Images Using Shearlet Transform (SHT) 66
- 3.3.5 Discrete Shearlet Transform (DST) 67
- 3.3.6 Shearlet Decompaction and Reconstruction 69
- 3.3.7 Shearlet and Wavelet Comparison 71
- 3.3.8 Complex Shearlet Transform 74
- 3.3.9 Complex Shearlet Transform for Image Enhancement 78
- 3.3.10 Low and High frequencies of Complex Shearlet Transform for Image Denoising 79

3.4 General Comparison of Single/Multilevel Methods and Selection of Methods for Noise Removal and Image Enhancement 87

- 3.5 Application of Preprocessing 88
- 3.5.1 Pavement Surface Drainage Condition Assessment 88
- 3.6 Summary and Conclusion 93
- 3.7 Questions and Exercises 94

# 4 Fuzzy and Its Recent Advances 97

4.1 Introduction 97

- 4.1.1 Type-1 Fuzzy Set Theory 97
- 4.1.2 Type-2 Fuzzy Set Theory 98
- 4.1.3 α-Plane Representation of General Type-2 Fuzzy Sets 99
- 4.1.4 Type-Reduction 101
- 4.1.5 Defuzzification 103
- 4.1.6 Type-3 Fuzzy Logic Sets 105

- 4.2 Ambiguity Modeling in the Fuzzy Methods 106
- 4.2.1 Background of General Type-2 Fuzzy Sets 106
- 4.3 Theory of Automatic Methods for MF Generation 110
- 4.3.1 Automatic Procedure to Generate a 3D Membership Function 110
- 4.4 Steps and Components of General 3D Type-2 Fuzzy Logic Systems (G3DT2 FL) 111
- 4.4.1 General 3D Type-2 Fuzzy Logic Systems (G3DT2 FL) 111
- 4.5 General 3D Type-2 Polar Fuzzy Method 118
- 4.5.1 Automatic MF Generator 118
- 4.5.2 A Measure of Ultrafuzziness 119
- 4.5.3 Theoretic Operations of 3D Type-2 Fuzzy Sets in the Polar Frame 122
- 4.5.4 Representation of Fuzzy 3D Polar Rules 123
- 4.5.5  $\vartheta$ -Slice and  $\alpha$  Planes 123
- 4.6 Computational Performance (CP) 128
- 4.7 Application of G3DT2FLS in Pattern Recognition 129
- 4.7.1 Examples of the Application of Fuzzy Methods in Infrastructure Management 129
- 4.8 Summary and Conclusion 136
- 4.9 Questions and Exercises 138
- Further Reading 138

#### 5 Automatic Detection and Its Applications in Infrastructure 141

- 5.1 Introduction 141
- 5.1.1 Photometric Hypotheses (PH) 142
- 5.1.2 Geometric and Photometric Hypotheses (GPH) 143
- 5.1.3 Geometric Hypotheses (GH) 143

- 5.1.4 Transform Hypotheses (TH) 143
- 5.2 The Framework for Automatic Detection of Abnormalities in Infrastructure Images 144
- 5.2.1 Wavelet Method 144
- 5.2.2 High Amplitude Wavelet Coefficient Percentage (HAWCP) 144
- 5.2.3 High-Frequency Wavelet Energy Percentage (HFWEP) 146
- 5.2.4 Wavelet Standard Deviation (WSTD) 147
- 5.2.5 Moments of Wavelet 148
- 5.2.6 High Amplitude Shearlet Coefficient Percentage (HASHCP) 148
- 5.2.7 High-Frequency Shearlet Energy Percentage (HFSHEP) 156
- 5.2.8 Fractal Index 160
- 5.2.9 Moments of Complex Shearlet 164
- 5.2.10 Central Moments q 168
- 5.2.11 Hu Moments 169
- 5.2.12 Bamieh Moments 174
- 5.2.13 Zernike Moments 177
- 5.2.14 Statistic of Complex Shearlet 186
- 5.2.15 Contrast of Complex Shearlet 186
- 5.2.16 Correlation of Complex Shearlet 189
- 5.2.17 Uniformity of Complex Shearlet 189
- 5.2.18 Homogeneity of Complex Shearlet 189
- 5.2.19 Entropy of Complex Shearlet 191
- 5.2.20 Local Standard Deviation of Complex Shearlet Index (F\_Local\_STD) 193
- 5.3 Summary and Conclusion 197

5.4 Questions and Exercises 202

Further Reading 203

## 6 Feature Extraction and Fragmentation Methods 213

- 6.1 Introduction 213
- 6.2 Low-Level Feature Extraction Methods 213
- 6.3 Shape-Based Feature (SBF) 216
- 6.3.1 Center of Gravity (COG) or Center of Area (COA) 216
- 6.3.2 Axis of Least Inertia (ALI) 217
- 6.3.3 Average Bending Energy 218
- 6.3.4 Eccentricity Index (ECI) 218
- 6.3.5 Circularity Ratio (CIR) 220
- 6.3.6 Ellipse Variance Feature (EVF) 220
- 6.3.7 Rectangularity Feature (REF) 222
- 6.3.8 Convexity Feature (COF) 223
- 6.3.9 Euler Number Feature (ENF) 223
- 6.3.10 Profiles Feature (PRF) 224
- 6.4 1D Function-Based Features for Shape Representation 225
- 6.4.1 Complex Coordinates Feature (CCF) 226
- 6.4.2 Extracting Edge Characteristics Using Complex Coordinates 226
- 6.4.3 Edge Detection Using Even and Odd Shearlet Symmetric Generators 228
- 6.4.4 Object Detection and Isolation Using the Shearlet Coefficient Feature (SCF) 230
- 6.5 Polygonal-Based Features (PBF) 231
- 6.6 Spatial Interrelation Feature (SIF) 231

6.7 Moments Features (MFE) 231

6.8 Scale Space Approaches for Feature Extraction (SSA) 231

6.9 Shape Transform Features (STF) 231

6.9.1 Radon Transform Features (RTF) 231

6.9.2 Linear Radon Transform 233

6.9.3 Translation of RT 235

6.9.4 Scaling of RT 235

6.9.5 Point and Line Transform Using RT 235

6.9.6 RT in Sparse Objects 238

6.9.7 Point and Line in RT 238

6.10 Various Case-Based Examples in Infrastructures Management 241

6.10.1 Case 1: Feature Extraction from Polypropylene Modified Bitumen Optical Microscopy Images 241

6.10.2 Ratio of Number of Black Pixels to the Number of Total Pixels (RBT) 245

6.10.3 Ratio of Number of Black Pixels to the Number of Total Pixels in Watershed Segmentation (RWS) 246

6.10.4 Number and Average Area of the White Circular Objects in the Binary Image (The number of circular objects [NCO] & ACO) 250

6.10.5 Entropy of the Image 250

6.10.6 Radon Transform Maximum Value (RTMV) 252

6.10.7 Entropy of Radon Transform (ERT) 253

6.10.8 High Amplitude Radon Percentage (HARP) 255

6.10.9 High-Energy Radon Percentage (HERP) 257

6.10.10 Standard Deviation of Radon Transform (STDR) 258

6.10.11 Q th -Moment of Radon Transform (QMRT) 262

6.10.12 Case 2: Image-Based Feature Extraction for Pavement Skid Evaluation 262

6.10.13 Case 3: Image-Based Feature Extraction for Pavement Texture Drainage Capability Evaluation 269

6.10.14 Case 4: Image-Based Features Extraction in Pavement Cracking Evaluation 279

6.10.15 Automatic Extraction of Crack Features 281

6.10.16 Extraction of Crack Skeleton Using Shearlet Complex Method 281

6.10.17 Calculate Crack Width Feature Using External Multiplication Method 282

6.10.18 Detection of Crack Starting Feature (Crack Core) Using EPA Emperor Penguin Metaheuristic Algorithm 284

6.10.19 Selection of Crack Root Feature Based on Geodetic Distance 286

6.10.20 Determining Coordinates of the Crack Core as the Optimal Center at the Failure Level using EPA Method 289

6.10.21 Development of New Features for Crack Evaluation Based on Graph Energy 292

6.10.22 Crack Homogeneity Feature Based on Graph Energy Theory 299

6.10.23 Spall Type 1 Feature: Crack Based on Graph Energy Theory in Crack Width Mode 299

6.10.24 General Crack Index Based on Graph Energy Theory 301

6.11 Summary and Conclusion 306

6.12 Questions and Exercises 307

Further Reading 308

## 7 Feature Prioritization and Selection Methods 313

7.1 Introduction 313

7.2 A Variety of Features Selection Methods 313

7.2.1 Filter Methods 315

7.2.2 Correlation Criteria 315

7.2.3 Mutual Information (MI) 315

7.2.4 Wrapper Methods 318

7.2.5 Sequential Feature Selection (SFS) Algorithm 318

- 7.2.6 Heuristic Search Algorithm (HAS) 320
- 7.2.7 Embedded Methods 320
- 7.2.8 Hybrid Methods 323
- 7.2.9 Feature Selection Using the Fuzzy Entropy Method 326

7.2.10 Hybrid-Based Feature Selection Using the Hierarchical Fuzzy Entropy Method 327

7.2.11 Step 1: Measure Similarity Index and Evaluate Features 331

7.2.12 Step 2: Final Feature Vector 337

7.3 Classification Algorithm Based on Modified Support Vectors for Feature Selection – CDFESVM 337

- 7.3.1 Methods for Determining the Fuzzy Membership Function in Feature Selection 341
- 7.4 Summary and Conclusion 348
- 7.5 Questions and Exercises 349

Further Reading 350

## 8 Classification Methods and Its Applications in Infrastructure Management 353

- 8.1 Introduction 353
- 8.2 Classification Methods 354
- 8.2.1 Naive Bayes Classification 355
- 8.2.2 Decision Trees 360
- 8.2.3 Logistic Regression 365
- 8.2.4 k-Nearest Neighbors (kNN) 367
- 8.2.5 Ensemble Techniques 367
- 8.2.6 Adaptive Boosting (AdaBoost) 370

8.2.7 Artificial Neural Network 373

- 8.2.8 Support Vector Machine 378
- 8.2.9 Fuzzy Support Vector Machine (FSVM) 379
- 8.2.10 Twin Support Vector Machine (TSVM) 380
- 8.2.11 Fuzzy Twin Support Vector Machine (FTSVM) 381
- 8.2.12 Entropy and Its Application FSVM 381

8.2.13 Development of Entropy Fuzzy Coordinate Descent Support Vector Machine (efcdsvm)383

- 8.2.14 Development of a New Support Vector Machine in Polar Frame (PSVM) 384
- 8.2.15 Case Study: Pavement Crack Classification Based on PSVM 388
- 8.3 Summary and Conclusion 396
- 8.4 Questions and Exercises 399

Further Reading 399

## 9 Models of Performance Measures and Quantification in Automation 405

- 9.1 Introduction 405
- 9.2 Basic Definitions 407
- 9.2.1 Confusion Matrix 407
- 9.2.2 Main Metrics 407
- 9.2.3 Accuracy Indexes 408
- 9.2.4 Time (Speed) 408
- 9.3 Database Modeling and Model Selection 409
- 9.3.1 Different Parts of the Data 409
- 9.3.2 Cross Validation 410
- 9.3.3 Regularization Techniques and Overfitting 410

9.4 Performance Evaluations and Main Metrics 411

9.4.1 General Statistics 411

9.4.2 Basic Rations 411

9.4.3 Rations of Ratios 412

9.4.4 Additional Statistics 413

9.4.5 Operating Characteristic 414

9.5 Case Studies 415

9.5.1 Case 1: The Confusion Matrix for Evaluating Drainage of Pavement Surface 416

9.5.2 Case 2: Metrics for Pavement Creak Detection Based on Deep Learning Using Transfer Learning 417

9.5.3 Case 3: The Confusion Matrix for Evaluating Pavement Crack Classification 420

9.5.4 Case 4: Quality Evaluation for Determining Bulk Density of Aggregates 425

9.6 Summary and Conclusion 429

9.7 Questions and Exercises 430

Further Reading 431

## 10 Nature-Inspired Optimization Algorithms (NIOAs) 437

10.1 Introduction 437

10.2 General Framework and Levels of Designing Nature-Inspired Optimization Algorithms (NIOAs) 438

10.3 Basic Principles of Important Nature-Inspired Algorithms (NIOAs) 439

10.3.1 Genetic Algorithm (GA) 440

10.3.2 Particle Swarm Optimization (PSO) Algorithm 441

10.3.3 Artificial Bee Colony (ABC) Algorithm 444

10.3.4 Bat Algorithm (BA) 446

10.3.5 Immune Algorithm (IA) 448

10.3.6 Firefly Algorithm (FA) 451

10.3.7 Cuckoo Search (CS) Algorithm 452

10.3.8 Gray Wolf Optimizer (GWO) 454

10.3.9 Krill Herd Algorithm (KHA) 455

10.3.10 Emperor Penguin Algorithms (EPA) 458

10.3.11 Hybrid Optimization Methods 467

10.4 Summary and Conclusion 470

10.5 Questions and Exercises 470

Further Reading 471

Appendix A Data Sets and Codes 475

Appendix B The Glossary of Nature-Inspired Optimization Algorithms (NIOAS) 477

Appendix C Sample Code for Feature Selection 483

Index 521