



REMOTE SENSING AND IMAGE INTERPRETATION

Fourth Edition

Thomas M. Lillesand

University of Wisconsin—Madison

Ralph W. Kiefer

University of Wisconsin—Madison



John Wiley & Sons, Inc.

New York Chichester Weinheim

Brisbane Singapore Toronto



CONTENTS

1 **Concepts and Foundations of Remote Sensing 1**

- 1.1 Introduction 1
- 1.2 Energy Sources and Radiation Principles 4
- 1.3 Energy Interactions in the Atmosphere 9
- 1.4 Energy Interactions with Earth Surface Features 12
- 1.5 Data Acquisition and Interpretation 23
- 1.6 Reference Data 27
- 1.7 The Global Positioning System 33
- 1.8 An Ideal Remote Sensing System 35
- 1.9 Characteristics of Real Remote Sensing Systems 37

- 1.10 Successful Application of Remote Sensing 41
- 1.11 Land and Geographic Information Systems 44
- 1.12 Organization of the Book 52
Selected Bibliography 52

2 **Elements of Photographic Systems 56**

- 2.1 Introduction 56
- 2.2 Early History of Aerial Photography 57
- 2.3 Basic Negative-to-Positive Photographic Sequence 59
- 2.4 Film Exposure 61

- 2.5 Film Density and Characteristic Curves 69
- 2.6 Spectral Sensitivity of Black and White Films 81
- 2.7 Color Film 85
- 2.8 Color Infrared Film 89
- 2.9 Filters 93
- 2.10 Aerial Film Cameras 98
- 2.11 Film Resolution 107
- 2.12 Electronic Imaging 111
- 2.13 Aerial Videography 117
- 2.14 Multiband Imaging 118
- 2.15 Conclusion 122
- Selected Bibliography 122

3 Basic Principles of Photogrammetry 125

- 3.1 Introduction 125
- 3.2 Basic Geometric Characteristics of Aerial Photographs 128
- 3.3 Photographic Scale 136
- 3.4 Ground Coverage of Aerial Photographs 142
- 3.5 Area Measurement 142
- 3.6 Relief Displacement of Vertical Features 148
- 3.7 Image Parallax 155
- 3.8 Ground Control for Aerial Photography 165
- 3.9 Mapping with Aerial Photographs 167
- 3.10 Flight Planning 182
- 3.11 Conclusion 186
- Selected Bibliography 189

4 Introduction to Visual Image Interpretation 190

- 4.1 Introduction 190
- 4.2 Fundamentals of Visual Image Interpretation 191
- 4.3 Basic Visual Image Interpretation Equipment 201
- 4.4 Land Use/Land Cover Mapping 208
- 4.5 Geologic and Soil Mapping 219
- 4.6 Agricultural Applications 230
- 4.7 Forestry Applications 236
- 4.8 Rangeland Applications 246
- 4.9 Water Resource Applications 248
- 4.10 Urban and Regional Planning Applications 261
- 4.11 Wetland Mapping 263
- 4.12 Wildlife Ecology Applications 267
- 4.13 Archaeological Applications 277
- 4.14 Environmental Assessment 280
- 4.15 Principles of Landform Identification and Evaluation 282
- Selected Bibliography 303

5 Multispectral, Thermal, and Hyperspectral Sensing 309

- 5.1 Introduction 309
- 5.2 Across-Track Scanning 310
- 5.3 Along-Track Scanning 314
- 5.4 Operating Principles of Across-Track Multispectral Scanners 316
- 5.5 Example Along-Track Multispectral Scanner and Data 319
- 5.6 Across-Track Thermal Scanning 322

- 5.7 Thermal Radiation Principles 325
- 5.8 Interpreting Thermal Scanner Imagery 334
- 5.9 Geometric Characteristics of Across-Track Scanner Imagery 345
- 5.10 Geometric Characteristics of Along-Track Scanner Imagery 356
- 5.11 Radiometric Calibration of Thermal Scanners 357
- 5.12 Temperature Mapping with Thermal Scanner Data 361
- 5.13 FLIR Systems 361
- 5.14 Hyperspectral Sensing 363
- 5.15 Conclusion 370
 - Selected Bibliography 370

6 Earth Resource Satellites Operating in the Optical Spectrum 373

- 6.1 Introduction 373
- 6.2 Early History of Space Imaging 374
- 6.3 Landsat Satellite Program Overview 376
- 6.4 Landsat-1, -2, and -3 377
- 6.5 Landsat-4 and -5 391
- 6.6 Landsat-6 Planned Mission 399
- 6.7 Landsat-7 400
- 6.8 Landsat Image Interpretation 401
- 6.9 New Millennium Program 415
- 6.10 SPOT Satellite Program 416
- 6.11 SPOT-1, -2, and -3 416
- 6.12 SPOT-4 422
- 6.13 SPOT-5 423
- 6.14 SPOT Image Interpretation 425

- 6.15 Other Moderate Resolution Land Satellites 431
- 6.16 High Resolution Land Satellites 435
- 6.17 Hyperspectral Satellite Systems 439
- 6.18 Meteorological Satellites 441
- 6.19 Ocean Monitoring Satellites 451
- 6.20 Earth Observing System 456
- 6.21 Space Station Remote Sensing 465
 - Selected Bibliography 466

7 Digital Image Processing 470

- 7.1 Introduction 470
- 7.2 Image Rectification and Restoration 473
- 7.3 Image Enhancement 488
- 7.4 Contrast Manipulation 489
- 7.5 Spatial Feature Manipulation 499
- 7.6 Multi-Image Manipulation 513
- 7.7 Image Classification 532
- 7.8 Supervised Classification 534
- 7.9 The Classification Stage 536
- 7.10 The Training Stage 544
- 7.11 Unsupervised Classification 555
- 7.12 Hybrid Classification 559
- 7.13 Classification of Mixed Pixels 561
- 7.14 The Output Stage 565
- 7.15 Postclassification Smoothing 566
- 7.16 Classification Accuracy Assessment 568
- 7.17 Data Merging and GIS Integration 575
- 7.18 Hyperspectral Image Analysis 592
- 7.19 Biophysical Modeling 597

- 7.20** Scale Effects 598
- 7.21** Image Transmission and Compression 603
- 7.22** Conclusion 605
 - Selected Bibliography 605

8 **Microwave Sensing 616**

- 8.1** Introduction 616
- 8.2** Radar Development 617
- 8.3** Side Looking Radar System Operation 619
- 8.4** Synthetic Aperture Radar 628
- 8.5** Geometric Characteristics of Side-Looking Radar Imagery 630
- 8.6** Transmission Characteristics of Radar Signals 636
- 8.7** Other Radar Image Characteristics 641
- 8.8** Radar Image Interpretation 644
- 8.9** Radar Remote Sensing from Space 666

- 8.10** Seasat-1 667
- 8.11** Shuttle Imaging Radar 668
- 8.12** Almaz-1 676
- 8.13** ERS-1, ERS-2, and Envisat-1 677
- 8.14** JERS-1 and ALOS 680
- 8.15** Radarsat 682
- 8.16** LightSAR 687
- 8.17** Spaceborne Radar System Summary 687
- 8.18** Interferometric Radar 687
- 8.19** Planetary Exploration 691
- 8.20** Passive Microwave Sensing 692
- 8.21** Lidar 700
 - Selected Bibliography 706

Appendix 711

- Remote Sensing Data Sources 711
- Remote Sensing Periodicals 713

Index 715
