Contents

In Memoriam *ix*

Preface to the First Edition *xi*

Preface to the Second Edition *xiii*

Preface to the Third Edition *xvii*

Preface to the Fourth Edition *xix*

Preface to the Fifth Edition *xxi*

List of Examples *xxiii*

1 Remote Sensing: Basic Principles **1**

1.1 Introduction 1

1.2 Electromagnetic Radiation and Its Properties 5

1.2.1 Terminology 5

1.2.2 Nature of Electromagnetic Radiation 6

1.2.3 The Electromagnetic Spectrum 7

1.2.4 Sources of Electromagnetic Radiation 14

1.2.5 Interactions with the Earth's Atmosphere 16

1.3 Interaction with Earth Surface Materials 18

1.3.1 Introduction 18

1.3.2 Spectral Reflectance of Earth Surface Materials 20

1.4 Summary 27

References 27

2 Remote Sensing Platforms and Sensors **31**

2.1 Introduction 31

2.2 Characteristics of Imaging Remote Sensing Instruments 34

2.2.1 Spatial Resolution 34

2.2.2 Spectral Resolution 37

2.2.3 Radiometric Resolution 39

2.3 Optical, Near-infrared, and Thermal Imaging Sensors 42

2.3.1 Along-track Scanning Radiometer (ATSR) 42

2.3.2 Advanced Very High Resolution Radiometer (AVHRR) and Visible Infrared Imager Radiometer Suite (VIIRS) 42

2.3.3 MODIS (MODerate Resolution Imaging Spectrometer) 44

2.3.4 Ocean Observing Instruments 44

2.3.5 IRS LISS 48

2.3.6 Landsat Instruments 48

2.3.7 SPOT Sensors 53

2.3.8 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 55

2.3.9 ESA Sentinel Programme 58

2.3.10 High-resolution Commercial and Small Satellite Systems 59

2.4 Microwave Imaging Sensors 62
2.4.1 European Space Agency Synthetic Aperture Spaceborne Radars 66
2.4.2 Radarsat 67
2.4.3 TerraSAR-X and COSMO-SkyMed 68
2.4.4 ALOS PALSAR 69
2.4.5 Sentinel-1 SAR 70
2.5 Summary 70
References 70

3 Preprocessing of Remotely Sensed Data 75
3.1 Introduction 75
3.2 Cosmetic Operations 76
3.2.1 Missing Scan Lines 77
3.2.2 De-striping Methods 78
3.3 Geometric Correction and Registration 80
3.3.1 Orbital Geometry Model 82
3.3.2 Transformation Based on Ground Control Points 84
3.3.3 Resampling Procedures 94
3.3.4 Image Registration 97
3.3.5 Other Geometric Correction Methods 97
3.4 Atmospheric Correction 98
3.4.1 Background 98
3.4.2 Image-based Methods 99
3.4.3 Radiative Transfer Model 100
3.4.4 Empirical Line Method 101
3.5 Illumination and View Angle Effects 102
3.6 Sensor Calibration 103
3.7 Terrain Effects 108
3.8 Summary 109
References 109

4 Image Enhancement Techniques 117
4.1 Introduction 117
4.2 Human Visual System 118
4.3 Contrast Enhancement 120
4.3.1 Linear Contrast Stretch 120
4.3.2 Histogram Equalisation 121
4.3.3 Gaussian Stretch 129
4.4 Pseudocolour Enhancement 133
4.4.1 Density Slicing 133
4.4.2 Pseudocolour Transform 134
4.5 Summary 137
References 137

5 Image Transforms 139
5.1 Introduction 139
5.2 Arithmetic Operations 140
5.2.1 Image Addition 141
5.2.2 Image Subtraction 141
5.2.3 Image Multiplication 142
5.2.4 Image Division and Vegetation Indices 143
5.3 Empirically Based Image Transforms 148
5.3.1 Perpendicular Vegetation Index 148
5.3.2 Tasselled Cap (Kauth–Thomas) Transformation 149

5.4 Principal Component Analysis 152
5.4.1 Standard Principal Component Analysis 152
5.4.2 Noise-adjusted Principal Component Analysis 160
5.4.3 Decorrelation Stretch 162
5.5 Hue, Saturation, and Intensity (HSI) Transform 162
5.6 The Discrete Fourier Transform 164
5.6.1 Introduction 164
5.6.2 Two-dimensional Fourier Transform 166
5.6.3 Applications of the Fourier Transform 169
5.7 The Discrete Wavelet Transform 172
5.7.1 Introduction 172
5.7.2 The One-dimensional Discrete Wavelet Transform 172
5.7.3 Two-dimensional Discrete Wavelet Transform 177
5.8 Change Detection 179
5.8.1 Introduction 179
5.8.2 NDVI Difference Image 180
5.8.3 Principal Component Analysis 180
5.8.4 Canonical Correlation Change Analysis 182
5.8.5 Time Series Analysis 185
5.8.6 Summary 191
5.9 Image Fusion 191
5.9.1 Introduction 191
5.9.2 Hue, Saturation, and Intensity (HSI) Algorithm 193
5.9.3 Principal Component Analysis 193
5.9.4 Gram–Schmidt Orthogonalisation 193
5.9.5 Wavelet-based Methods 193
5.9.6 Evaluation: Subjective Methods 193
5.9.7 Evaluation: Objective Methods 196
5.10 Summary 197
References 197

6 Filtering Techniques 205
6.1 Introduction 205
6.2 Spatial-domain Low-pass (Smoothing) Filters 206
6.2.1 Moving Average Filter 206
6.2.2 Median Filter 210
6.2.3 Adaptive Filters 212
6.3 Spatial-domain High-pass (Sharpening) Filters 215
6.3.1 Image Subtraction Method 215
6.3.2 Derivative-based Methods 216
6.4 Spatial-domain Edge Detectors 220
6.5 Frequency-domain Filters 222
6.6 Summary 228
References 228

7 Classification 231
7.1 Introduction 231
7.2 Geometrical Basis of Classification 233
7.3 Unsupervised Classification 235
7.3.1 The *k*-Means Algorithm 235
7.3.2 ISODATA 236
7.3.3 A Modified *k*-Means Algorithm 237
7.4 Supervised Classification 242
7.4.1 Training Samples 242

	7.4.2	Statistical Classifiers	247
	7.4.3	Neural Classifiers	252
7.5	Subpixel Classification Techniques		259
	7.5.1	The Linear Mixture Model	260
	7.5.2	Spectral Angle Mapping	265
	7.5.3	Independent Component Analysis	266
	7.5.4	Fuzzy Classifiers	267
7.6	More Advanced Approaches to Image Classification		268
	7.6.1	Support Vector Machines	268
	7.6.2	Decision Trees	270
	7.6.3	Other Methods of Classification	271
7.7	Incorporation of Non-spectral Features		273
	7.7.1	Texture	273
	7.7.2	Use of External Data	276
7.8	Contextual Information		277
7.9	Feature Selection		278
7.10	Classification Accuracy		281
7.11	Summary		284
References			285
8	**Advanced Topics**		**297**
8.1	Introduction		297
8.2	SAR Interferometry		297
	8.2.1	Basic Principles	297
	8.2.2	Interferometric Processing	302
	8.2.3	Problems in SAR Interferometry	304
	8.2.4	Applications of SAR Interferometry	305
8.3	Imaging Spectroscopy		306
	8.3.1	Introduction	306
	8.3.2	Processing Imaging Spectroscopy Data	309
8.4	Lidar		327
	8.4.1	Introduction	327
	8.4.2	Lidar Details	330
	8.4.3	Lidar Applications	332
8.5	Summary		335
References			335
Appendix A	**Computing for Remote Sensing**		**341**
Index			**347**