

Contents

1	Introduction	1
1.1	Spectral Imaging	2
1.1.1	Basic Principles	2
1.1.2	Applications of Spectral Imaging Technology	4
1.2	Multi-band Polarization Imaging	5
1.2.1	Development of Multi-band Polarization Imaging	5
1.2.2	Applications of Multi-band Polarization Imaging	7
	References	9
2	Polarization Imaging	13
2.1	Electromagnetics and Polarization	13
2.1.1	Maxwell's Equations	13
2.1.2	Polarization Ellipse	15
2.1.3	Fresnel's Equations	17
2.2	Principles of Polarization Imaging	18
2.3	Polarization Imaging for Object Recognition	21
2.3.1	Object Detection and Tracking	22
2.3.2	Edge Detection	22
2.3.3	Object Classification and Recognition	24
2.4	Factors Affecting Polarization Imaging	26
2.4.1	Transmission of Polarized Light	27
2.4.2	Lighting	29
2.5	Reduction of Measurement Errors	30
2.5.1	Multi-angle Measurement	30
2.5.2	Image Filtering	32
2.5.3	Image Fusion	32
2.6	Micro-polarizer Array Imaging	36
2.6.1	Micro-polarizer Array	36
2.6.2	Experiment Results	41
	References	45

3	Multi-band Polarization Imaging	47
3.1	Multi-band Polarization Imaging Methods	47
3.1.1	Spectral Band Tuning	47
3.1.2	Polarization Adjustment	49
3.2	Multi-band Polarization Imagers Based on Tunable Filters	50
3.2.1	Liquid Crystal Tunable Filters	51
3.2.2	Acousto-Optic Tunable Filters	52
3.2.3	Liquid Crystal Variable Retarders	52
3.2.4	Typical Multi-band Polarization Imaging Systems	53
3.3	Multi-band Polarization Imagers Using LCTF	55
3.3.1	Implementation of Multi-band Polarization Imaging Systems	55
3.3.2	Main Devices of Multi-band Polarization Imaging Systems	56
3.3.3	Multi-band Polarization Imaging Sensors	57
3.4	Calibration of Multi-band Polarization Imaging Systems	60
3.4.1	Spectral Band Calibration	60
3.4.2	Spectral Radiometric Calibration	61
3.4.3	Mechanical Revolving Filters	61
3.4.4	Polarization Calibration	62
3.5	Reconstruction of Multi-band Polarization Imagery	63
3.5.1	Spectral Inversion Methods	63
3.5.2	Polarization Inversion Based on Empirical Linear Method	65
3.6	Experiment Settings	66
	References	71
4	Multi-band Polarization Bidirectional Reflectance Distribution Function	73
4.1	Bidirectional Reflectance Distribution Function	73
4.1.1	Measurement of Bidirectional Reflectance	75
4.1.2	Bidirectional Reflectance Model	79
4.2	Polarization BRDF	81
4.2.1	Polarization BRDF Functions	81
4.2.2	Polarized Radiative Transfer Function	82
4.3	Polarization BRDF Measurements	85
4.3.1	Measuring Principles	85
4.3.2	Outdoor Polarization BRDF Measurement Systems	87
4.3.3	Imaging Data Inversion	87
4.3.4	Experiment Procedures	88
4.3.5	Simulation Results and Analysis	89
4.4	Polarization BRDF Model of Coated Targets	93
4.4.1	Intensity Component Model of Coated Targets	93
4.4.2	DoLP Model of Coated Targets	95

- 4.4.3 Relationships of Polarization BRDF, Azimuth Angle,
and Wavelength 98
 - 4.5 Polarization BRDF Model of the Background 100
 - 4.5.1 Intensity Component Model of the Background. 101
 - 4.5.2 DoLP Model of the Background 104
 - References 109
- 5 Object Detection with Multi-band Polarization Imaging. 111**
 - 5.1 Multi-band Polarization Image Analysis 111
 - 5.2 Object Detection 112
 - 5.2.1 Polarization Mixture Model 112
 - 5.2.2 Multivariate Gaussian Distribution. 114
 - 5.2.3 Maximum Likelihood Estimation. 114
 - 5.2.4 Likelihood Ratio Test 115
 - 5.2.5 Subspace Analysis. 119
 - 5.2.6 Stochastic Signal and Entropy. 121
 - 5.2.7 Nonparametric Kernel Density Estimation. 122
 - 5.3 Anomaly Detection Methods 124
 - 5.3.1 Statistical Hypothesis Model for Anomaly Detection 125
 - 5.3.2 Low Probability Target Detection 126
 - 5.3.3 Classical RX Detection Algorithm. 126
 - 5.3.4 Improved RX Detection Algorithm 127
 - 5.4 Fuzzy Integral Fusion Detection of Band Subsets 128
 - 5.4.1 Data Model and Band Subset Division. 128
 - 5.4.2 Fuzzy Measure and Fuzzy Integral 129
 - 5.4.3 Nonparametric Fuzzy Membership Functions 130
 - 5.4.4 Fuzzy Density Estimation. 131
 - 5.4.5 Experiment Results 134
 - 5.5 Multi-detector Maximum Entropy Fusion Hypothesis
Detection 135
 - 5.5.1 Single Likelihood Hypothesis Detection Model 135
 - 5.5.2 Kernel Density Estimation 136
 - 5.5.3 Detector Fusion Based on Maximum Entropy 137
 - 5.5.4 Experiment Results 140
 - 5.6 Fusion Detection Based on Polarization and Spectral Features. . . 141
 - 5.6.1 Fusion Detection Algorithms. 141
 - 5.6.2 Experiment Results 144
 - 5.7 Fusion Detection Based on DoLP Modulation 146
 - 5.7.1 DoLP Modulation Fusion 147
 - 5.7.2 False Color Coding Fusion of Spectral
and Polarization Images 150
 - References 152

6	Bio-inspired Multi-band Polarization Imaging	155
6.1	Multi-band Polarization Vision	155
6.1.1	Polarization Vision	155
6.1.2	Compound Eye	156
6.2	Bio-inspired Multi-band Polarization Vision Model	158
6.2.1	Multi-band Polarization Vision Model	158
6.2.2	Heterogeneous Multi-band Polarization Imaging CCD Array Systems	160
6.3	Multi-band Polarization Vision Systems	161
6.3.1	Design of Multi-band Polarization Vision Systems	161
6.3.2	Multi-band Polarization Vision System Software	163
6.4	Spectral and Polarization Information Recovery for FOV Expansion	164
6.4.1	Low-Rank Matrix Recovery	165
6.4.2	Estimation of Missing Spectral and Polarization Information	166
6.4.3	FOV Expansion with Estimated Spectral and Polarization Information	168
6.4.4	Experiment Results	169
	References	174
7	3D Reconstruction and Dehazing with Polarization Vision	177
7.1	3D Reconstruction	177
7.1.1	Background	177
7.1.2	3D Reconstruction with Polarization Vision	179
7.1.3	3D Reconstruction Results	182
7.2	Instant Image Dehazing	184
7.2.1	Physical Models and Properties	186
7.2.2	Image Dehazing Using Polarization Information	189
7.2.3	Experiment Results	191
	References	193