Robot Vision

Video-based Indoor Exploration with Autonomous and Mobile Robots



Contents

List of Figures XI

Symbols and Abbreviations $\ XV$

1	Introduction 1	
2	Image Processing 9	
2.1	Color Models 10	
2.2	Filtering 11	
2.2.1	Kalman Filter 11	
2.2.2	Gabor Filter 13	
2.2.3	Application of the Gabor Filter 16	
2.3	Morphological Image Processing 22	
2.3.1	The Structuring Element 22	
2.3.2	Erosion 23	
2.3.3	Dilation 23	
2.4	Edge Detection 24	
2.5	Skeleton Procedure 28	
2.6	The Segmentation of Image Regions 28	
2.7	Threshold 29	
3	Navigation 33	
3.1	Coordinate Systems 33	
3.2	Representation Forms 36	
3.2.1	Grid-based Maps 36	
3.2.2	Graph-based Maps 37	
3.3	Path Planning 38	
3.3.1	Topological Path Planning 38	
3.3.2	Behavior-based Path Execution 39	
3.3.3	Global Path Planning 39	
3.3.4	Local Path Planning 40	
3.3.5	The Combination of Global and Local Path Planning	40

Contents	
3.4	The Architecture of a Multilevel Map Representation 42
3.5	Self-localization 43
4	Vision Systems 47
4.1	The Human Visual Apparatus 47
4.1.1	The Functionality 47
4.1.2	The Visual Cortex 48
4.2	The Human Visual Apparatus as Model for Technical Vision Systems 49
4.2.1	Attention Control 50
4.2.2	Passive Vision 51
4.2.3	Active Vision 51
4.2.4	Space-variant Active Vision 52
4.3	Camera Types 53
4.3.1	Video Cameras 53
4.3.2	CCD Sensors 53
4.3.3	Analog Metric Cameras 55
5	CAD 57
5 5.1	Constructive Solid Geometry 57
5.1 5.2	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58
5.1	Constructive Solid Geometry 57
5.1 5.2	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58
5.1 5.2 5.3	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60
5.1 5.2 5.3 5.3.1	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60
5.1 5.2 5.3 5.3.1 5.3.2	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3 5.7	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74 Partial Depth Reconstruction 74
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3 5.7 5.7.1 5.7.2	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74 Partial Depth Reconstruction 74 Three-dimensional Reconstruction with Edge Gradients 75
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3 5.7 5.7.1 5.7.2 5.7.3	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74 Partial Depth Reconstruction 74 Three-dimensional Reconstruction with Edge Gradients 75 Semantic Reconstruction 77
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3 5.7 5.7.1 5.7.2	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74 Partial Depth Reconstruction 74 Three-dimensional Reconstruction with Edge Gradients 75
5.1 5.2 5.3 5.3.1 5.3.2 5.3.3 5.4 5.5 5.6 5.6.1 5.6.2 5.6.3 5.7 5.7.1 5.7.2 5.7.3	Constructive Solid Geometry 57 Boundary-representation Schema (B-rep) 58 Approximate Models 59 Octrees 60 Extended Octrees 60 Voxel Model 61 Hybrid Models 62 Procedures to Convert the Models 62 The Use of CAD in Computer Vision 63 The Approximation of the Object Contour 64 Cluster Search in Transformation Space with Adaptive Subdivision 66 The Generation of a Pseudo-B-rep Representation from Sensor Data 71 Three-dimensional Reconstruction with Alternative Approaches 74 Partial Depth Reconstruction 74 Three-dimensional Reconstruction with Edge Gradients 75 Semantic Reconstruction 77

5.7.2 Three-dimensional Reconstruction with Edge Gradients 75 5.7.3 Semantic Reconstruction 77 5.7.4 Mark-based Procedure 83 6 Stereo Vision 87 6.1 Stereo Geometry 87 6.2 The Projection of the Scene Point 90 6.3 The Relative Motion of the Camera 92 6.4 The Estimation of the Fundamental Matrix B 93 6.5 Image Rectification 95 6.6 Ego-motion Estimation 97 6.7 Three-dimensional Reconstruction by Known Internal Parameters

6.8	Three-dimensional Reconstruction by Unknown Internal and External Parameters 98
6.8.1	Three-dimensional Reconstruction with Two Uncalibrated Cameras 98
6.8.2	Three-dimensional Reconstruction with Three or More Cameras 100
6.9	Stereo Correspondence 105
6.9.1	Correlation-based Stereo Correspondence 106
6.9.2	Feature-based Stereo Correspondence 106
6.10	Image-sequence Analysis 109
6.11	Three-dimensional Reconstruction from Image Sequences with the
0.2=	Kalman Filter 110
7	Camera Calibration 113
7.1	The Calibration of One Camera from a Known Scene 114
7.1.1	Pinhole-camera Calibration 114
7.1.2	The Determination of the Lens Distortion 116
7.2	Calibration of Cameras in Robot-vision Systems 118
7.2.1	Calibration with Moving Object 120
7.2.2	Calibration with Moving Camera 121
8	Self-learning Algorithms 123
8.1	Semantic Maps 124
8.2	Classificators for Self-organizing Neural Networks 125
9	OCR 129
10	Redundancy in Robot-vision Scenarios 133
10.1	Redundant Programs for Robot-vision Applications 134
10.2	The Program 135
10.2.1	Looking for a Rectangle 136
10.2.2	Room-number Recognition 137
10.2.3	Direct Recognition of Digits 138
10.2.4	The Final Decision 139
10.3	The Program Flow 140
10.4	Experiment 142
10.5	Conclusion 144
11	Algorithm Evaluation of Robot-vision Systems for Autonomous Robots 147
11.1	Algorithms for Indoor Exploration 148
11.1.1	Segmentation with a Gabor Filter 150
11.1.2	Segmentation with Highpass Filtering 152
11.1.3	Object Selection with a Band Filter 153
11.1.4	Object Detection with the Color Feature 153
11.1.5	Edge Detection with the Sobel Filter 155
11.2	Experiments 156
11.3	Conclusion 157

Contents

12	Calibration for Autonomous Video-based Robot Systems 159	
12.1	Camera Calibration for Indoor Exploration 160	
12.2	Simple Calibration with SICAST 160	
12.2.1	Requirements 160	
12.2.2	Program Architecture 161	
12.3	Experiments 164	
12.4	Conclusion 165	
13	Redundant Robot-vision Program for CAD Modeling 167	
13.1	New CAD Modeling Method for Robot-vision Applications 10	68
13.1.1	Functionality 168	
13.1.2	Program Architecture 172	
13.2	Experiment 182	
13.3	Conclusion 184	

Bibliography 185

Index 193