

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

3.4	The Architecture of a Multilevel Map Representation	42
3.5	Selflocalization	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
5.1	Constructive Solid Geometry	57
5.2	Boundary-representation Schema (B-rep)	58
5.3	Approximate Models	59
5.3.1	Octrees	60
5.3.2	Extended Octrees	60
5.3.3	Voxel Model	61
5.4	Hybrid Models	62
5.5	Procedures to Convert the Models	62
5.6	The Use of CAD in Computer Vision	63
5.6.1	The Approximation of the Object Contour	64
5.6.2	Cluster Search in Transformation Space with Adaptive Subdivision	66
5.6.3	The Generation of a Pseudo-B-rep Representation from Sensor Data	71
5.7	Three-dimensional Reconstruction with Alternative Approaches	74
5.7.1	Partial Depth Reconstruction	74
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	98

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 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	Classifiers 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

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 168

13.1.1 Functionality 168

13.1.2 Program Architecture 172

13.2 Experiment 182

13.3 Conclusion 184

Bibliography 185

Index 193