Contents

- Series Foreword xi Figures xiii Tables xxix Preface xxxi
- 1 Introduction 1
- 2 **Projective Geometry** 7
 - 2.1 How to read this chapter 8
 - 2.2 Projective spaces 9
 - 2.3 The projective line 13
 - 2.4 The projective plane 14
 - 2.5 The projective space 23
 - 2.6 Problems 30
- 3 Modeling and Calibrating Cameras 33
 - 3.1 A guide to this chapter 33
 3.2 Modeling cameras 33
 3.3 Changing coordinate systems 41
 3.4 Calibrating cameras 51
 - 3.5 Problems 66

(

4

5

6

vi

Contents

Edge Detection 69 4.1 Introduction and precursors 69 4.2 Computing derivatives and smoothing 77 4.3 One-dimensional edge detection by the maxima of the first derivative 90 4.4 Discrete implementations 104 4.5 Two-dimensional edge detection by the maxima of the gradient magnitude 108 4.6 More references 118 4.7 Problems 119 **Representing Geometric Primitives and Their Uncertainty** 125 5.1 How to read this chapter 126 5.2 Manifolds 127 5.3 The two-dimensional case 130 5.4 The three-dimensional case 135 5.5 Three-dimensional displacements 142 5.6 Computing uncertainty 151 5.7 Problems 162 Stereo Vision 165 6.1 Correspondence ambiguity; tokens and features 165 6.2 Constraints 169 6.3 Rectification 188 6.4 Correlation techniques 189 6.5 Relaxation techniques 196 6.6 Dynamic programming 198 6.7 Prediction and verification 201 6.8 Adding the planarity constraint 206 6.9 Using three cameras 211 6.10 Reconstructing points and lines in three dimensions 230

6.11 More references 240

6.12 Problems 240

vii

Contents

Determining Discrete Motion from Points and Lines 245 7 7.1 How to read this chapter 245 7.2 Introduction 247 7.3 Determining camera displacement from point correspondences 247 7.4 Determining displacement from line correspondences 283 7.5 Determining the displacement of a planar patch 289 7.6 Problems 297 Tracking Tokens over Time 301 8 8.1 Introduction 301 8.2 Recursive least-squares and Kalman filtering methods 302 8.3 Two-dimensional token tracking 318 8.4 Three-dimensional token tracking 326 8.5 Conclusion and references 338 8.6 Problems 338 9 Motion Fields of Curves 341 9.1 How to read this chapter 341 9.2 Optical flow and the motion field 343 9.3 The motion fields of a curve 350 9.4 Rigid motion of a 3-D straight line 369 9.5 Rigid motion of a 3-D curve 380 9.6 Some simple examples 387 9.7 Constraining stereo matches 394 9.8 More references 399 9.9 Problems 400 10 Interpolating and Approximating Three-Dimensional Data 403 10.1 The status of the problem 403 10.2 How to read this chapter 411 10.3 Shape topologies 412 10.4 Delaunay triangulation 415

Contents

- 10.5 Constrained Delaunay triangulation 438
- 10.6 Application: building polyhedral interpolations 448
- 10.7 Finding surface patches 471
- 10.8 More references 476
- 10.9 Problems 477
- 11 Recognizing and Locating Objects and Places 483
 - 11.1 The status of the problems 483
 - 11.2 Various approaches to the problems 484
 - 11.3 Recognizing and determining the pose of 2-D objects 497
 - 11.4 Recognizing and determining the pose of 3-D objects 515
 - 11.5 Optical navigation and model building for a mobile
 - robot 534
 - 11.6 Problems 556

12 Answers to Problems 559

- 12.1 Answers to problems of chapter 2 559
- 12.2 Answers to problems of chapter 3 567
- 12.3 Answers to problems of chapter 4 573
- 12.4 Answers to problems of chapter 5 578
- 12.5 Answers to problems of chapter 6 586
- 12.6 Answers to problems of chapter 7 592
- 12.7 Answers to problems of chapter 8 597
- 12.8 Answers to problems of chapter 9 600
- 12.9 Answers to problems of chapter 10 605
- 12.10 Answers to problems of chapter 11 615
- **Constrained Optimization** 623 Α
- Some Results from Algebraic Geometry 625 B
 - B.1 Plane curves 625
 - B.2 The degree of an algebraic manifold 627
 - B.3 Resultants 627

ix

Differential Geometry 629 C C.1 Plane curves 629 C.2 Space curves 629 C.3 Surface patches 630

Bibliography 635

Index 659