

Contents

| | |
|---|-----------|
| Summary | 3 |
| Theory | 3 |
| Implementation | 5 |
| Validation | 6 |
| Introduction | 7 |
| Structure of the Exposition | 8 |
| 1 The Problem and Its Background | 11 |
| 1.1 Computer Vision | 11 |
| 1.2 The Marr Paradigm | 12 |
| 1.3 The Visual Modules | 13 |
| 1.4 Ill-posed Problems in Early Vision | 14 |
| 1.5 The Communication Approach | 15 |
| 1.5.1 The Bottom-up Approach | 16 |
| 1.5.2 The Top-down Approach | 16 |
| 1.5.3 The MIT Vision Machine | 16 |
| 1.5.4 Bayesian Integration | 17 |
| 1.5.5 Active Vision | 18 |
| 1.5.6 Knowledge Based Integration | 18 |
| 1.5.7 Discussion of Integration Approaches | 18 |
| 1.6 Performance Characterization | 19 |
| 1.7 The Biological Background | 19 |
| 1.8 Principles and Objectives | 21 |
| 1.9 Summary | 22 |
| 2 A Possible Solution | 23 |
| 2.1 Requirements | 23 |
| 2.2 The Representation Problem | 25 |
| 2.3 The Planar Patch | 27 |
| 2.4 Analysis of Error Propagation | 28 |
| 2.4.1 The Abstract Model of a Visual Module | 28 |
| 2.4.2 Solution of Simple Special Cases | 29 |
| 2.4.3 General Case | 29 |
| 2.4.4 Solution of the Constrained Case | 30 |
| 2.5 Monte Carlo Simulation | 30 |

| | | |
|----------|--|-----------|
| 2.5.1 | Algorithm Validation | 30 |
| 2.6 | The Communication Method | 31 |
| 2.7 | Limitations and Extensions | 32 |
| 2.8 | Summary | 32 |
| 3 | Data Fusion | 33 |
| 3.1 | System Model | 37 |
| 3.2 | Distance Measures | 39 |
| 3.3 | The General Data Fusion Problem | 40 |
| 3.4 | Covariance Intersection | 41 |
| 3.5 | Markov Random Field Theory | 42 |
| 3.6 | The Segmentation of the Regions | 45 |
| 3.7 | Improvement of the Plane Equations | 47 |
| 3.8 | Summary | 47 |
| 4 | Reclustering | 49 |
| 4.1 | Introduction | 51 |
| 4.2 | The Algorithm | 51 |
| 4.3 | Applications to Early Vision | 53 |
| 4.3.1 | Disparity Estimation | 53 |
| 4.3.2 | Optical Flow Computation | 55 |
| 4.4 | Noise Sensitivity | 55 |
| 4.5 | Synthetic and Natural Scenes | 58 |
| 4.6 | Limitations | 60 |
| 4.7 | More Advanced Reclustering Schemes | 60 |
| 4.8 | Similar Approaches | 63 |
| 4.9 | Discussion of the Reclustering Algorithm | 64 |
| 4.10 | Summary | 65 |
| 5 | System Description | 67 |
| 5.1 | Coordinate Systems | 69 |
| 5.2 | Camera Modeling | 72 |
| 5.2.1 | Camera Modeling and Projective Geometry | 73 |
| 5.3 | Camera Calibration | 75 |
| 5.4 | Noise Estimation | 76 |
| 5.5 | Stereo Vision | 77 |
| 5.5.1 | The Correspondence Problem | 78 |
| 5.5.2 | Feature-based Stereo Algorithms | 79 |
| 5.5.3 | Area-based Stereo Algorithms | 80 |
| 5.5.4 | Phase-difference Stereo | 84 |
| 5.6 | The Optical Flow Module | 86 |
| 5.7 | The Floor-lines-matcher | 88 |
| 5.8 | Summary | 90 |

| | |
|--|------------|
| 6 Implementation | 91 |
| 6.1 Design Objectives | 93 |
| 6.2 History of the Project | 94 |
| 6.3 The Role of Java | 94 |
| 6.4 Design by Contract | 95 |
| 6.4.1 Against Defensive Programming | 96 |
| 6.4.2 Demanding or Tolerant? | 96 |
| 6.5 Design Patterns | 97 |
| 6.5.1 The Observer Pattern | 98 |
| 6.5.2 The Facade Pattern | 99 |
| 6.5.3 The Singleton Pattern | 99 |
| 6.6 The neurop2 Package | 100 |
| 6.6.1 The neurop2.test Package | 101 |
| 6.6.2 The neurop2.string Package | 101 |
| 6.6.3 The neurop2.math Package | 101 |
| 6.6.4 The neurop2.image Package | 102 |
| 6.6.5 The neurop2.geometry Package | 103 |
| 6.6.6 The neurop2.widgets Package | 104 |
| 6.7 The COMVIS System | 104 |
| 6.7.1 The comvis.source Package | 105 |
| 6.7.2 The comvis.patch Package | 105 |
| 6.7.3 The comvis.vision Package | 108 |
| 6.7.4 The comvis.fusion Package | 111 |
| 6.7.5 The comvis.world Package | 113 |
| 6.7.6 The comvis.log Package | 113 |
| 6.7.7 The Classes in the Root comvis Package | 113 |
| 6.8 Summary | 114 |
| 7 Validation and Experiments | 115 |
| 7.1 The Test Image Generator | 115 |
| 7.2 The Differential Stereo Algorithm | 117 |
| 7.3 The Differential Motion Algorithm | 118 |
| 7.4 The Phase-based Stereo Algorithm | 122 |
| 7.4.1 Error Measures | 123 |
| 7.4.2 Range Test | 124 |
| 7.4.3 Contrast Test | 124 |
| 7.4.4 Camera Sensitivity Imbalance Test | 124 |
| 7.4.5 Noise Test | 129 |
| 7.4.6 Choice of the Thresholds T_1 and T_2 | 130 |
| 7.4.7 Spectral Content | 130 |
| 7.4.8 Evaluation of the Results | 133 |
| 7.5 Stereo Algorithms Comparison | 133 |
| 7.6 Validation on Real Scenes | 134 |
| 7.6.1 The CIL Sequences | 134 |
| 7.7 Summary | 140 |

| | |
|--|------------|
| 8 Conclusions | 155 |
| 8.1 Problems and Limitations | 156 |
| 8.2 Extensions | 157 |
| A Proof of CI Consistency | 159 |
| B Covariance Propagation Proofs | 161 |
| B.1 The Abstract Model of a Computer Vision Module | 161 |
| B.2 Proof of the Unconstrained Case Solution | 161 |
| B.3 Proof of the Constrained Case Solution | 163 |