Contents

Keywords iii

Abstract vii

Zusammenfassung ix

Table of Contents xi

List of Figures xiv

List of Tables xvi

List of Algorithms xvii

Acknowledgements xxi

1 Introduction 1

1.1 Intelligent Robots . . . 1
1.2 Concepts of Autonomous Mobile Robot Navigation . . . 2
1.3 Navigation Strategies of Humans and Animals . . . 4
1.4 A Brief History of Robot Navigation . . . 5
1.5 Map-based Navigation . . . 6
1.5.1 Metric Maps . . . 7
1.5.2 Topological Maps . . . 8
1.6 Aims, Contributions and Scope of this Thesis . . . 9
1.6.1 Research Aims and Contributions . . . 9
1.6.2 Main Contributions . . . 11
1.6.3 Scope and Limitations of this Thesis . . . 12
1.7 Thesis Outline . . . 12

2 Autonomous Navigation **15**
2.1 Introduction . . . 15
2.2 Information Sources . . . 16
2.3 Map Representations . . . 17
2.3.1 Metric Maps . . . 17
2.3.2 Topological Maps . . . 20
2.4 Localisation . . . 21
2.4.1 Localisation Capacities . . . 21
2.4.2 Localisation Methods . . . 21
2.4.3 Single-Hypothesis Tracking . . . 23
2.4.4 Multi-Hypotheses Tracking . . . 25
2.5 Environment Mapping . . . 26
2.5.1 Mapping Challenges . . . 26
2.5.2 Metric Map Learning . . . 27
2.5.3 Topological Map Learning . . . 29
2.6 Simultaneous Localisation and Mapping . . . 33
2.7 Mapping Dynamic Environments . . . 34
2.8 Summary . . . 34

3 Visual Appearance-based Place Identification **37**
3.1 Introduction . . . 37
3.1.1 Contribution . . . 38
3.2 Fingerprints of Places . . . 39
3.2.1 Local Image Features . . . 39
3.2.2 Global Image Features . . . 41
3.3 Place Identification using Colour Histograms . . . 49
3.3.1 Appearance-based Fingerprints of Places . . . 49
3.3.2 Self-Organising Maps for Place Identification . . . 50
3.3.3 Similarity Metrics . . . 52
3.4 Results from Experiments . . . 53
3.4.1 Experimental Setup . . . 53
3.4.2 Distance Histograms . . . 54
3.4.3 Results . . . 56
3.5 Discussion . . . 60

4 Appearance-based Localisation **63**
4.1 Introduction . . . 63
4.1.1 Contribution . . . 64
4.2 Topological Map . . . 64
4.3 Localisation . . . 65
4.3.1 Bayesian Filters for Localisation . . . 65
4.3.2 Monte-Carlo Localisation . . . 66
4.3.3 Posterior Position Estimation . . . 68
4.3.4 Kidnapped Robot Strategy . . . 68

4.4 Results from Experiments . . . 70
4.4.1 Experimental Setup . . . 70
4.4.2 Localisation . . . 70
4.5 Summary . . . 82

5 Map Induction using Neighbourhood Information 85
5.1 Introduction . . . 85
5.1.1 Contribution . . . 87
5.1.2 Related Work . . . 87
5.2 Neighbourhood Information for Topological Map Induction . . . 88
5.2.1 Local Adjacency Information: n-Grams . . . 89
5.2.2 n-Consistency . . . 90
5.3 Topological Mapping from a History . . . 90
5.3.1 Mapping Constraints . . . 90
5.3.2 Map Induction using a Stochastic Local Search . . . 91
5.4 Results from Experiments . . . 93
5.4.1 Artificial Random Graphs . . . 93
5.4.2 Connectivity Inference from Identified Places . . . 98
5.5 Chapter Summary . . . 105

6 Off-line SLAM for Map Induction 107
6.1 Introduction . . . 107
6.1.1 Contribution . . . 108
6.1.2 Related Work . . . 109
6.2 Topological off-line SLAM . . . 110
6.2.1 Map Likelihood Estimation using a Particle Filter . . . 110
6.2.2 Localisation . . . 112
6.3 Experiments . . . 112
6.3.1 Results from Experiments . . . 115
6.4 Summary . . . 119

7 Conclusions 121
7.1 Summary of Contributions . . . 121
7.2 Discussion and Further Work . . . 122
7.3 Final Conclusions . . . 123

A Scale-invariant Feature Transform 125

B Speed Up Robust Features 129

C Colour Spaces 133
C.1 RGB Colour Space . . . 133
C.2 HSI Colour Space . . . 134

D Bayesian Tracking **135**
D.1 Bayesian Tracking 136
D.2 Kalman Filter 136
D.3 Particle Filters 137

E Circular Mean **139**

Bibliography **141**