
Contents

Colophon	ii
Preface	v
1 Introduction	1
1.1 Studying Intracellular Dynamics	1
1.2 Fundamental Limitations in Microscopy	3
1.3 Tracking in Fluorescence Microscopy	6
1.3.1 Image Preprocessing	6
1.3.2 Object Localization	6
1.3.3 Solving the Correspondence Problem	8
1.3.4 Probabilistic Methods for Tracking	11
1.4 Analyzing Tracking Results	13
1.5 Thesis Outline	15
2 Quantitative Comparison of Spot Detection Methods in Fluorescence Microscopy	17
2.1 Introduction	18
2.2 Detection Framework for Fluorescence Microscopy	19
2.2.1 Image formation	19
2.2.2 Detection Framework	22
2.3 Detection Methods	23
2.3.1 Noise Reduction	23
2.3.2 Unsupervised Signal Enhancement	25
2.3.3 Supervised Signal Enhancement	29
2.3.4 Signal Thresholding and Performance Measures	32
2.4 Experimental results	33
2.4.1 Evaluation on Synthetic Image Data	33
2.4.2 Evaluation on Real Image Data	46
2.5 Discussion and Conclusions	50
3 Particle Filtering for Multiple Object Tracking in Dynamic Fluorescence Microscopy Images: Application to Microtubule Growth Analysis	53
3.1 Introduction	54
3.2 Microtubule Growth Analysis	57

3.3	Tracking Framework	58
3.3.1	Nonlinear Bayesian Tracking	58
3.3.2	Particle Filtering Methods	59
3.3.3	Multi-Modality and Mixture Tracking	60
3.4	Tailoring the Framework	61
3.4.1	State-Space and Dynamic Model	61
3.4.2	Object Interactions and Markov Random Field	63
3.4.3	Observation Model and Likelihood	63
3.4.4	Hierarchical Searching	66
3.4.5	Measurement Gating	67
3.4.6	Data-Dependent Sampling	68
3.4.7	Clustering and Track Management	69
3.4.8	Initialization and Track Initiation	70
3.5	Experimental Results	71
3.5.1	Evaluation on Synthetic Data	71
3.5.2	Evaluation on Real Data	77
3.6	Discussion and Conclusions	80
4	Multiple Object Tracking in Molecular Bioimaging by Rao-Blackwellized Marginal Particle Filtering	85
4.1	Introduction	86
4.2	Probabilistic Tracking Framework	88
4.2.1	Particle Filtering Approach	88
4.2.2	Multiple Object Tracking	89
4.2.3	Dynamics Models	90
4.2.4	Observation Model	92
4.2.5	Track Management	93
4.3	Incorporating Multiple Dynamics	94
4.4	Applying Marginalization Concepts	95
4.4.1	Filtering Distribution Marginalization	96
4.4.2	Data-Dependent Sampling	96
4.4.3	Rao-Blackwellization Approach	97
4.5	Algorithm Overview	98
4.6	Experimental Results	100
4.6.1	Considered Objects	100
4.6.2	Synthetic Data Experiments	101
4.6.3	Real Data Experiments	104
4.7	Discussion and Conclusions	109
5	Microtubule Dynamics Analysis using Kymographs and Variable-Rate Particle Filters	113
5.1	Introduction	114
5.2	Methods	115
5.2.1	<i>In Vitro</i> Microtubule Dynamics Model	115
5.2.2	Imaging Technique and Kymographs	116
5.2.3	Edge Preserving Smoothing	118

<i>Contents</i>	ix
5.2.4 Variable-Rate Particle Filtering	120
5.2.5 Multiscale Trend Analysis	125
5.3 Experimental Results	126
5.3.1 Evaluation on Synthetic Data	126
5.3.2 Evaluation on Real Data	131
5.4 Discussion and Conclusions	131
6 Summary	133
Bibliography	137
Samenvatting	147
PhD Portfolio	151
Publications	153
Curriculum Vitae	155