

Contents

Zusammenfassung	XI
Abstract	XIII
1 Introduction	1
1.1 Motivation	2
1.2 Aims and Content	5
2 Target Trajectory Prediction	9
2.1 Neural Network-based Approach	11
2.1.1 Methods	11
2.1.2 Experimental Setup	16
2.1.3 Simulation Results	18
2.2 Optimization-based Approach Enhanced with Intention Evaluation	22
2.2.1 Intention Evaluation-based Bayesian Path Waypoint Prediction	22
2.2.2 Optimization-based Trajectory Prediction	29
2.2.3 Simulation Results	34
3 Time Optimal Handover Trajectory Planning for Aerial Manipulators	41
3.1 Mechanics Fundamentals	42
3.1.1 Continuous-time Mechanics	42
3.1.2 Discrete Mechanics	44
3.2 Discrete Mechanics and Complementarity Constraints (DMCC) Framework	52
3.2.1 Framework Formulation	53
3.2.2 Case Study	54
3.3 Time-optimal Handover Trajectory Planning based on the DMCC Framework	65

3.3.1	Modeling of the Aerial Manipulator	66
3.3.2	Handover Opportunities	69
3.3.3	Simulation Study	72
4	Data-Augmented Model Predictive Control for Quadrotors	81
4.1	Model Predictive Control	82
4.1.1	Nominal Quadrotor Dynamics	84
4.1.2	Numerical Simulation	85
4.2	Gaussian Process Regression-augmented Nonlinear Model Predictive Control	85
4.2.1	Gaussian Process Regression Models	88
4.2.2	Training Procedure	91
4.2.3	NMPC with Augmented Dynamics Model	96
4.3	Software-in-the-Loop (SITL) Simulation	96
4.3.1	SITL Simulation	97
4.3.2	Simulation Results	97
5	Experiments	101
5.1	Arrangement of the Robotic Hardware Systems	101
5.1.1	Mobile Robots	101
5.1.2	Quadrotors	102
5.2	Localization based on the Visual Information	104
5.2.1	Methods	105
5.2.2	Autonomous Object Detection and Tracking System	109
5.2.3	Experiment Results	111
5.3	Target Trajectory Prediction Experiment	115
5.3.1	Experimental Setup	115
5.3.2	Neural Network-based Approach Results	115
5.3.3	Optimization-based Approach Results	119
5.4	Gaussian Process-augmented NMPC Experiment	122
5.4.1	Time-Variant Thrust Loss	127
5.4.2	Trajectory Tracking Performance	129

5.4.3	Static Object Grasping Experiment	131
5.5	Object Handover Experiment	136
5.5.1	Control Framework	136
5.5.2	Experimental Results	137
6	Conclusion and Outlook	143
	Abbreviations, Symbols, and Notation	147
	Bibliography	152