

Contents

Abstract 3

Zusammenfassung 5

Acknowledgments 7

List of Figures 12

List of Tables 15

List of symbols 17

List of Abbreviations 21

1 Introduction 23

1.1 Motivation 23

1.2 Use cases 24

1.3 Problem Description 24

1.4 Related Work 26

1.4.1 Prioritized Planning 26

1.4.2 Velocity Planning in Distance-Time-Space 27

1.4.3 Plan Execution under Disturbances 28

1.5 Technology Gap and Own Contribution 28

2 Fundamentals, Assumptions and Requirements 31

2.1 Environment 31

2.2 Vehicle Reference Model 32

2.3 Path Planning 34

2.4 Trajectory Planning 35

3	Identification of Dynamic Obstacles in Distance-Time-Space	37
3.1	Problem Formulation for Non-Point-Like Robots	38
3.2	Circular Vehicle Shape Approximation	39
3.3	Spatiotemporal Occupancy Tracking	39
3.3.1	Entry/Exit Matrices	41
3.3.2	Registration of Occupancy Intervals in an Occupancy Grid Map	43
3.4	Evaluation	44
3.5	Conclusion	45
4	Velocity Planning in Distance-Time-Space	47
4.1	Problem Formulation	47
4.1.1	Sampling-based Conflict Detection	47
4.1.2	Accuracy and Limitations	48
4.2	Prioritized Breadth-First Search (PBFS)	48
4.2.1	Implementation	49
4.2.2	Limitations	51
4.3	Advanced Prioritized Breadth-First Search (APBFS)	51
4.3.1	Principle	51
4.3.2	Implementation	53
4.4	Evaluation of Prioritized Breadth-First Search (PBFS) and Advanced Prioritized Breadth-First Search (APBFS)	53
4.4.1	Evaluation using Random Scenarios	56
4.4.2	Limitations	57
4.5	Genetic Algorithm for Velocity Planning (GVP)	59
4.5.1	Genotype-Phenotype-Mapping	60
4.5.2	Initial Population	64
4.5.3	Mutation and Selection	65
4.5.4	Fitness Function	65
4.5.5	Implementation	66
4.5.6	Parameter Tuning, Evaluation and Future Work	67
4.6	Conclusion	69
5	Adaptation of Planned Trajectories under Delaying Disturbances	71
5.1	Problem Formulation	71
5.2	State of the Art	73
5.2.1	Baseline Liveness-preserving Method ALLSTOP	73
5.2.2	Robust Multi-Robot Trajectory Tracking Strategy (RMTRACK)	74
5.2.3	RMTRACK with Flipping of Priorities	77
5.3	Robust Multi-Truck Trajectory Tracking Strategy (RMTRUCK)	77
5.3.1	Approach	77
5.3.2	Implementation	83

5.3.3	Evaluation	85
5.3.4	Limitations	89
5.4	Efficient Replanning of Individual Agents (SAFESTOP)	90
5.4.1	Approach	90
5.4.2	Evaluation	92
5.4.3	Limitations	96
5.5	Conclusion and Outlook	98
6	Deployment and Demonstration	99
6.1	Integration of the Proposed Algorithms into the OrchesTruck Webservice	99
6.2	The helyOS Control Tower Framework	101
6.3	Vehicle Automation Software Stack	103
6.4	Distributed Simulation	103
6.5	Case Study	105
6.5.1	Results when Applying RMTRUCK	108
6.5.2	Conclusion	109
7	Conclusion and Future Work	111
7.1	Future Work	112
A	Publications	119
A.1	Related Publications	119
A.1.1	In Proceedings of International Conferences, Peer-Reviewed	119
A.1.2	In Proceedings of Minor Conferences	120
A.2	Unrelated Publications	120
B	Supervised Student Theses	121
C	Credits	123