

Contents

Abstract	i
Zusammenfassung	iii
Disclaimer	v
Contents	vii
1 Introduction	1
1.1 Navigation Maps in Geodesy and the Automotive Domain	1
1.2 Challenges and Needs in Map-Based Driving	4
1.3 Research Objectives and Claims	6
2 3DHD CityScenes: A Novel LiDAR and HD Map Dataset	9
2.1 State of the Art	10
2.2 Dataset Properties of 3DHD CityScenes in Comparison	11
2.2.1 Overview of Dataset Properties	11
2.2.2 Comprehensiveness of Provided HD Map Annotations	13
2.2.3 Spatial Alignment of Sensor and Map Data	16
2.2.4 Completeness of HD Map Annotations	18
2.3 Metrics for Object Recognition	21
2.3.1 Object Detection and Classification	21
2.3.2 Bounding Shape Regression	21
2.4 Summary	22
3 A Novel Conceptual Framework for Dependable Maps	23
3.1 State of the Art	24
3.2 A Formalization of Maps	25
3.2.1 High-Definition Maps	25
3.2.2 Map Deviations: Types, Metrics, and Categories	28
3.3 A Systemic Approach to Dependable Maps	32
3.3.1 Map Safety	33
3.3.2 Map Availability	36
3.3.3 Map Reliability	37
3.3.4 System Framework for Achieving Map Dependability	38
3.4 Analysis of Map Deviations in Urban Domains	42
3.4.1 Estimation of Deviating Map Shares	42
3.4.2 Estimation of Map Change Rates	44
3.4.3 Estimation of Error Rate Metrics	46
3.4.4 Real-World Map Deviations	47
3.5 Summary	48

4	3DHDNet: A Novel Network Architecture for 3D Object Detection	49
4.1	State of the Art	50
4.1.1	Map Element Recognition	50
4.1.2	DNN-Based 3D Object Detection	52
4.1.3	Baselines: VoxelNet and PointPillars	52
4.2	A Novel Network Architecture	54
4.2.1	Overview of Processing Stages	54
4.2.2	Pre-Processing Stage	55
4.2.3	A Novel Network Processing Stage	56
4.2.4	Post-Processing Stage	63
4.2.5	Novel Anchor Designs for 3D Map Element Detection	63
4.2.6	Novel Matching Strategies	64
4.3	Experiments and Discussion	66
4.3.1	Experimental Setup	66
4.3.2	Training Procedure	69
4.3.3	Multitask Element Detection	70
4.3.4	Single-Task Element Detection	74
4.3.5	Multitask Element Recognition	75
4.3.6	Ablation Studies	80
4.4	Summary	85
5	Novel Methods for DNN-Based 3D Map Evaluation	87
5.1	State of the Art	88
5.2	Novel Methods	89
5.2.1	Set of Examined Map Deviations	89
5.2.2	Method Overview	90
5.2.3	ME-SC: Sensor-Only Object Detection	92
5.2.4	ME-MC: Map-Supported Object Detection	93
5.2.5	ME-M: Direct Map Evaluation	95
5.3	Experiments and Discussion	97
5.3.1	Experimental Setup	97
5.3.2	Training Procedure	100
5.3.3	Results of Proposed Methods	100
5.3.4	Ablation on Map Deviation Frequency in Training	108
5.3.5	Ablation on Map Deviation Frequency in Inference	112
5.3.6	Ablation on Robustness Against Degenerated Sensor Data	115
5.3.7	Ablation on Robustness Against Misalignment Errors	118
5.3.8	Ablation Using Baseline 3D Object Detectors	119
5.3.9	Discussion of Onboard Applications	121
5.4	Summary	123
6	Conclusions	125
A	Notations	131
B	Acronyms	137
C	Procedure for Improving Annotation Completeness	139

D System Requirements for Dependable Maps	141
E Augmentation Studies	143
E.1 Basic Augmentation Methods	143
E.2 Novel Augmentation Methods	145
E.3 Augmentation Setups	147
F Statistical Significance of Performance Results	149
G Ablation on Downstream Network Strides	151
H Map Trust: Driving Under Correct Map Assumptions	153
H.1 Novel Conceptual Framework for Map Trust Estimation	153
H.2 Estimating Road Model Trust for Map-Less Driving	161
I Supplementary Results	163
I.1 Completeness of HD Map Annotations	163
I.2 Augmentation Studies	165
I.3 Ablation on Point Cloud Encoding	170
I.4 Ablation on Downstream Network Filters	172
I.5 Ablation on Downstream Network Strides	173
I.6 Ablation on Upstream Network Filters	174
I.7 Ablation on Deviation Frequency in Training	175
I.8 Ablation on Deviation Frequency in Inference	176
I.9 Ablation on Robustness Against Degenerated Sensor Data	177
First Author Publications	179
Bibliography	181