Contents

1	Intro	oductio	n	1		
	1.1	.1 Motivation				
	1.2	Focus	and Contributions of the Thesis	2		
	1.3	Structi	are of the Thesis	4		
2	Advanced Driver Assistance Systems					
	2.1	Categorization and Regulatory Standards				
	2.2					
		2.2.1	Sensor Modules	10		
		2.2.2	Sensor Data Fusion	15		
	2.3	Know	ledge Base for Situation Evaluation	20		
		2.3.1	Studies on Pedestrian- and Truck-related Accidents	22		
		2.3.2	Pedestrian Motion Analysis	25		
3	The	oretical	Foundations and Methods	27		
_	3.1		Tracking	27		
		3.1.1	Bayesian State Estimation	27		
		3.1.2	Kalman Filter	30		
		3.1.3	Extended Kalman Filter	32		
		3.1.4	Multi-Object Tracking	33		
	3.2	JIPDA	-based Object Tracking and Existence Estimation	36		
		3.2.1	Probabilistic Data Association	36		
		3.2.2	Existence Estimation	38		
		3.2.3	Gating Method	40		
		3.2.4	Computation of Association Hypotheses with Gating	4 1		
		3.2.5	Hypotheses Tree for the JIPDA Implementation	43		
		3.2.6	Object Management in JIPDA Filtering	48		
		3.2.7	Algorithm Complexity and Real-Time Computation	49		
	3.3	Classi	fication and Parameter Estimation	50		
		3.3.1	Model Selection and Model Evaluation	54		
	3.4	Discrete Event Systems and Hybrid Automatons		56		
	3.5	Reachability Analysis				
	3.6		ov Chain Abstraction	61		
		3.6.1	Computation of Transition Probabilities	63		

		262	M. L. Cl. S. H. L.	
		3.6.2	Markov Chain Update	64
		3.6.3	Markov Chain Update with Uncertain Input	65
4	Impl	lement	ation of two Pedestrian Tracking Approaches	67
	4.1	Relate	ed Work on Sensor Fusion and Pedestrian Tracking .	67
		4.1.1	Existing Approaches for Automotive Pedestrian	
			Tracking	67
		4.1.2	Related Work on Sensor Fusion using Probabilistic	
			Data Association	69
		4.1.3	Existing Approaches for Tracking across Sensory	
			Blind Regions	70
	4.2	Syster	m Description	72
		4.2.1	Camera	7 3
		4.2.2	Frontal Radar Sensors	75
		4.2.3	Blind Spot Radar	78
		4.2.4	Laser Scanner	7 9
	4.3	Coord	linate Systems and Sensor Calibration	86
		4.3.1	Spatial Calibration	87
		4.3.2	Temporal Calibration	90
	4.4	Senso	r Measurement	92
		4.4.1	Measurement Results of the Camera	95
		4.4.2	Measurement Results of the LRR and SRR	96
		4.4.3	Measurement Results of the BSR	99
	4.5	Proce	ss and Measurement Models	99
		4.5.1	Pedestrian State Model	100
		4.5.2	Ego Motion Estimation	101
		4.5.3	Radar Measurement Model	103
		4.5.4	Camera Measurement Model	104
		4.5.5	Existence Models	106
	4.6	Track	Management	109
		4.6.1	EKF-JIPDA Track Management	109
		4.6.2	EKF-GNN Track Management and Object Confi-	
			dence Computation	110
	4.7	Track	ing across the Sensory Blind Region	111
5	Situ	ation l	Evaluation	113
	5.1	State	of the Art regarding Situation Assessment	114
		5.1.1	Related Work on Maneuver Classification and Tra-	
			jectory Prediction	114
		5.1.2	Related Approaches for Risk Assessment	118

	5.2	, , , , , , , , , , , , , , , , , , , ,	122		
			126		
			130		
		5.2.3 Path Prediction	133		
	5.3		134		
			135		
		5.3.2 Stochastic Reachable Sets of Road Users	137		
		5.3.3 Conditional Collision Probability	146		
6	Resi	ults	149		
	6.1	Object Tracking and Object Classification	149		
		6.1.1 Methods for the Evaluation of the State Estimation	151		
		6.1.2 Methods for the Evaluation of the Detection Perfor-			
		mance	153		
		6.1.3 Examples for pedestrian tracking with EKF-JIPDA			
		and EKF-GNN	156		
		6.1.4 Results of the Evaluation of the State Estimation	162		
		6.1.5 Results of the Evaluation of the Filter's Detection Performance	169		
			170		
	6.2	6.1.6 Conclusions from the Filter Comparison	1/0		
	6.2	Evaluation of the Maneuver Classification and Trajectory	177		
		Prediction Approach	173		
	6.3	Risk Assessment of Vulnerable Road Users	182		
		6.3.1 Computation of the Time-to-Collision	184		
		6.3.2 Collision Risk between the Ego Vehicle and Pedes-	404		
		trians in Exemplary Situations	186		
7	Con		19 3		
	7.1	Conclusion	193		
	7.2	Outlook	195		
Α	Арр	pendix	197		
	A.1	Selected Proprioceptive Sensors	197		
	A.2		198		
	A.3	Cross-Validation	199		
		Interval Computations	199		
		Least Squares Method for Partial Regression Lines	201		
		Flow Chart of the DBSCAN Algorithm	202		
		Measurement Results of Short Range Radar 2			
		Additional Tracking Scenarios	204		

Contents

Abbreviations and Symbols											
Bibliography	221										
List of Publications	236										
List of Patents	2 37										
List of Supervised Theses	2 37										