

Contents

Acknowledgements	ix
Agradecimientos	xi
Abstract	xiii
Resumen	xv
Resum	xvii
1 Introduction	1
1.1 Motivation	1
1.2 Objectives	3
1.3 Outline	4
1.4 Contributions	5
1.4.1 Quality Indicators of Scientific Research	6
1.4.2 Journal Articles	7
1.4.3 International Conferences	8
1.4.4 Collaborations in other Research Topics	9
1.4.5 Research Awards and International Stays	9
1.4.6 Research Projects Collaborations	10
	xix

I	Autonomous Driving	13
2	State of the Art: Autonomous Navigation and Control	15
2.1	Clothoid-based Path Generation and Planning	16
2.1.1	Clothoids as Transition Curves	17
2.1.2	Clothoids in Continuous-Curvature Paths	18
2.1.3	Clothoid Properties	20
2.1.4	Clothoid Approximation	21
2.2	Navigation and Control	22
2.2.1	Path Following	22
2.2.2	Obstacle Avoidance	24
3	Smooth Path Generation	27
3.1	Introduction	27
3.2	Continuous-Curvature Path Generation	28
3.2.1	Problem Statement	28
3.2.2	Preliminary Study	29
3.3	Single Continuous-Curvature Paths	31
3.4	Double Continuous-Curvature Paths	33
3.4.1	Standard Double Continuous-Curvature Path	33
3.4.2	DCC Path with Nonzero Curvature Profile	40
3.4.3	Comparing DCC with SCC and Dubins Paths	41
3.5	Conclusions	46
4	Smooth Control	47
4.1	Introduction	47
4.2	Pure-Pursuit based Control	50
4.2.1	Problem Statement	50
4.2.2	Control Scheme	51
4.2.3	Target Selection	52
4.2.4	Curvature Profile Generator	53
4.2.5	Speed Profile Generator	54

4.2.6	Benchmarking: Results and Discussion	54
4.3	Optimal Control	59
4.3.1	Introduction	61
4.3.2	Problem Definition	63
4.3.2.1	Duality of Estimation and Control	64
4.3.2.2	Iterative Linearisation-based Optimal Control	66
4.3.3	Nonlinear Quadratic Control via Estimation	68
4.3.3.1	Linear Quadratic Regulator from KL Cost	68
4.3.3.2	Solution of the Dual Problem	70
4.3.3.3	Rauch-Tung-Striebel Nonlinear Controller	70
4.3.3.3.1	Computation of Nonlinear Control Law	71
4.3.3.3.2	ERTS Control Algorithm	72
4.3.3.3.3	URTS Control Algorithm	74
4.3.4	Benchmarking: Trajectory Tracking in Wheeled Robots	74
4.3.4.1	Analysis Setup	76
4.3.4.2	Mean-cost and Worst-cost Ratios	77
4.3.4.3	Computational Resources	79
4.3.5	DCC Path as Reference	80
4.4	Conclusions	83
5	Smooth Control Applications	85
5.1	Introduction	85
5.2	Vision-Based Line Following	86
5.3	Vehicle Stability Control	91
5.3.1	Stability Controller	92
5.3.2	Simulation: Results and Discussion	96
5.4	Obstacle Avoidance	102
5.4.1	Quasi-Holonomic Smooth Trajectories	103
5.4.2	Performance Analysis	107
5.5	Optimal Trajectory Following	110
5.6	Conclusions	114

II	Manual-Assisted Driving	117
6	State of the Art: Advanced Driver Assistance Systems	119
6.1	Accidents in Passenger Transportation Systems	119
6.2	Need for Solutions	121
6.3	Advanced Driver Assistance Systems	122
6.3.1	ADAS Classification	123
6.3.1.1	Braking Assistance	124
6.3.1.2	Stability Assistance	126
6.3.1.3	Visibility Enhancement	127
6.3.1.4	Advanced Navigation	129
6.4	Driving Assistance Through Haptic and Audiovisual Feedback . .	132
7	Driver Assistance Methodology	137
7.1	Introduction	137
7.2	Proposed Methodology for Driver Assistance	138
7.2.1	Collision Detection	139
7.2.1.1	Obstacle Space from Arc Reachable Manifold .	139
7.2.1.2	Obstacle Space from Clothoid Reachable Manifold	142
7.2.2	Risk Evaluation	146
7.2.3	Warning and Braking Assistance Algorithm	149
7.3	Conclusions	150
8	Pedestrian Detection and HAV Feedback in Real Bus	151
8.1	Introduction	151
8.2	Pedestrian Detection	151
8.3	Description of Safety Devices	156
8.3.1	Haptic Feedback	157
8.3.1.1	Haptic Pedal	157
8.3.1.2	Haptic Steering Wheel	161
8.3.2	Audio-Visual Feedback	164

8.3.3	Emergency Brake	165
8.4	Testing in Real Bus	166
8.4.1	Bus Prototype	166
8.4.2	Bus Model	170
8.4.3	Validation of Throttle Feedback and Emergency Braking	173
8.4.4	Validation of Steering Feedback	175
8.5	Conclusions	176
9	Driver Assistance Benchmarking	179
9.1	Introduction	179
9.2	Driving Simulation Cabin	179
9.3	Experimental Setup	181
9.4	Results	186
9.4.1	Emergency braking: mass influence	186
9.4.2	Haptic warning: distance influence	187
9.4.3	Haptic warning: driving behaviour influence	188
9.4.4	Emergency in an arrival manoeuvre	190
9.4.5	Emergency in a departure manoeuvre	193
9.4.6	Benchmarking Evaluation	193
9.4.6.1	Haptic Throttle and Emergency Braking	193
9.4.6.2	Haptic Steering Wheel	199
9.4.6.3	Usability	201
9.5	Discussion	202
9.6	Conclusions	204
10	Conclusions and Future Work	207
10.1	Conclusions	208
10.2	Achievements	210
10.3	Future Work	211
10.3.1	Spatial Smooth Paths	211
10.3.2	Clothoid Reachable Manifold Mathematics	212
10.3.3	Driver Guidance in Parking Manoeuvres	212

10.3.4 Haptic and Audio-Visual Feedback Benchmarking	212
Bibliography	213
A Preliminary Study of Spatial Smooth Paths	237