

Contents

Acknowledgement	ix
Agraïments	xi
Abstract	xiii
Resum	xv
Resumen	xvii
List of Terms	xxxiii
1 Introduction	1
Motivations	2
Contributions and Manuscript Outline	2
2 State of the Art	7
2.1 Multi-rate Estimation and Control	7
2.1.1 Periodic Modelling	8
2.1.2 Multi-rate Estimation based on Holds	9
2.1.2.1 Dual-rate High Order Holds based on Primitive Functions	11
2.1.2.2 Dual-rate Dynamic Model based Holds.	14
2.1.3 Multi-rate Control	15
2.1.3.1 Multi-rate PID	16
2.1.3.2 Multi-rate Linear Quadratic Regulator	17
2.2 Nonlinear Optimal Control	19
2.2.1 Receding Horizon Control	20
2.2.2 Iterative Linear Quadratic Regulator	21
2.2.3 Extended Rauch-Tung-Striebel Controller	22
2.3 Visual Feedback Control	26
2.3.1 Camera-robot Configurations	26

2.3.2	Task Functions in Visual Feedback Control	26
2.3.2.1	Camera Space Control	27
2.3.2.2	Joints Space Control	28
2.3.3	Features Selection	28
2.3.3.1	Geometric Features	29
2.3.3.2	Luminance/Photometric Features	30
2.3.3.3	Moment Features	30
2.3.4	The Interaction Matrix	32
2.3.5	Visual Feedback Control Laws	33
2.3.5.1	2D Visual Feedback Control	33
2.3.5.2	3D Visual Feedback Control	34
2.3.6	Problems in Visual Feedback Control	35
2.3.6.1	Local Minima	35
2.3.6.2	Singularity	36
2.3.6.3	Feature Visibility	36
2.3.7	Multi-rate Visual Feedback Control	37
3	Visual Feedback Control based on DR-HOHs	39
3.1	Motivation	39
3.2	Visual feedback wheeled robot control based on DR-HOHs . .	40
3.3	Visual Feedback Robot Control based on DR-HOHs	47
3.3.1	Results under Simulation	49
3.3.2	Experimental Results	51
3.4	Asyn. Dual-rate High Order Holds with Time Delay Compens- ation	53
3.4.1	Concepts and Formulation	54
3.4.2	Data Estimation from Vision Systems	59
3.4.2.1	Simulated results	59
3.4.2.2	Experimental results	63
3.4.3	Visual Feedback Robot Control based on Asyn. DR- HOH-TDC	66
3.5	Summary	76
3.6	Discussion	77
4	Visual Feedback Control based on DR-NLHOHs	81
4.1	Motivation	81
4.2	Multi-rate Nonlinear Holds	82
4.2.1	Methodology	84
4.2.2	Example	86
4.3	Visual Feedback Wheeled Robot Control based on DR-NLHOHs	89

4.4	Visual Feedback Robot Manipulator Control based on DR-NLHOHs	94
4.4.1	Results	97
4.5	Summary	101
5	VFC based on Reference Features Filtering Strategy	103
5.1	Motivation	103
5.2	Reference features filtering control strategy	104
5.2.1	Kalman Filter (KF)	105
5.2.2	Extended Kalman Filter/Smother (EKFS)	106
5.2.3	Visual Feedback Control	107
5.3	Dual-rate reference filtering control strategy	110
5.3.1	Dual-rate Kalman Filter (DR-KF)	110
5.3.2	Dual-sampling Extended Kalman Filter/Smother (DS-EKFS)	111
5.3.3	Visual Feedback Control	115
5.4	Analysis and results	116
5.4.1	Simulation Results	116
5.4.2	Experimental Results	123
5.5	Summary	135
6	Conclusions and Perspectives	137
6.1	Contributions	137
6.1.1	Sensor latency issue	137
6.1.2	On providing suitable trajectories issue	138
6.2	Perspectives	139
A	Experimental Platforms	141
A.1	Real platforms	144
A.1.1	Industrial Robotic Cells	144
A.1.1.1	Robot KR5 sixx R650	144
A.1.1.2	Robot Agilus R900 sixx	146
A.1.1.3	Supplementary Tools	147
A.1.1.4	On Externally Control of Kuka Robots	151
A.1.1.5	Software	156
A.1.1.6	Applications Highlights	156
A.1.2	SUMMIT Mobile Robot Platform	160
A.2	Virtual platforms	162
A.2.1	Industrial Robotic Cell Simulator	162
A.2.2	SUMMIT Mobile Platform Simulator	164
	References	167