

Contents

1. Introduction	1
1.1 Six-DOF Interaction Tasks	1
1.1.1 Operational space approach	2
1.1.2 Task space approach	2
1.2 Task Space Motion Control	3
1.2.1 Resolved acceleration control	3
1.2.2 Representation singularities	3
1.3 Task Space Interaction Control	4
1.3.1 Impedance control	5
1.3.2 Force control	5
1.4 PRISMA Lab Experimental Setup	6
1.4.1 Robot manipulators	6
1.4.2 Open control architecture	7
1.4.3 Force/torque sensor	8
2. Task Space Motion Control	11
2.1 Modelling	11
2.2 Resolved Acceleration Control	13
2.2.1 Euler angles	15
2.2.2 Alternative Euler angles	16
2.2.3 Angle/axis	18
2.2.4 Quaternion	21
2.3 Comparison	23
2.3.1 Computational issues	23
2.3.2 Experiments	24
3. Task Space Impedance Control	29
3.1 Indirect Force Control	29
3.2 Impedance Equation in the Operational Space	29
3.2.1 Translational impedance	30
3.2.2 Rotational impedance based on Euler angles	32
3.2.3 Rotational impedance based on alternative Euler angles	33
3.3 Impedance Equation in the Task Space	34
3.3.1 Rotational impedance based on angle/axis	35

3.3.2	Rotational impedance based on quaternion	38
3.4	Impedance Control Law	40
3.4.1	Operational space control	41
3.4.2	Task space control	42
3.4.3	Experiments	42
3.5	Redundant Manipulators	50
3.5.1	Stabilization of internal motion	52
3.5.2	Experiments	53
4.	Task Space Force Control	57
4.1	Direct Force Control	57
4.1.1	Hybrid approach	58
4.1.2	Parallel approach	59
4.1.3	Force control with inner motion loop	59
4.2	Task Space Parallel Control	61
4.2.1	Experiments	65
5.	Applications to a Dual-Robot System	69
5.1	Cooperative Manipulation	69
5.2	Loose Cooperative Control	70
5.2.1	Modular control structure	70
5.2.2	Experiments	71
5.3	Tight Cooperative Control	77
5.3.1	Task space formulation	77
5.3.2	Object-level impedance control	79
5.3.3	Experiment	80
6.	Conclusion and future research directions	83
	References	86
A.	Orientation of a Rigid Body	91
A.1	Non-minimal Representations	91
A.1.1	Rotation matrix	91
A.1.2	Unit quaternion	93
A.2	Mutual Orientation	95
A.3	Angular Velocity	96
B.	Real-Time Implementation Notes	99
B.1	The main control loop	99
B.1.1	C3G and PC interfacing	99
B.1.2	Force sensor interfacing	101
B.1.3	Safety checks	101
B.2	Writing the C-code	102
	Index	107



<http://www.springer.com/978-3-540-00159-1>

Interaction Control of Robot Manipulators

Six degrees-of-freedom tasks

Natale, C.

2003, XIV, 108 p., Hardcover

ISBN: 978-3-540-00159-1