
Contents

1. Introduction	1
1.1 Robot Arm Structure	1
1.2 Coordinate Systems and Frames	2
1.3 Some Common Robot Manipulators.....	3
1.3.1 Articulated Robots (RRR).....	3
1.3.2 Spherical Robot (RRP).....	4
1.3.3 SCARA Robot (RRP)	4
1.3.4 Cylindrical Robot (RPP)	4
1.3.5 Cartesian Robot (PPP)	5
1.4 Getting Started with Scilab and RTSX	5
1.4.1 Scilab basics	5
1.4.2 Simulation by Xcos	9
1.4.3 RTSX Installation	10
1.5 Book Structure	11
Problems.....	12
2. Homogeneous Transformation	13
2.1 Rotation in 3-D.....	13
2.2 Composition of Rotations	15
2.2.1 Rotation about the Current Frame.....	15
2.2.2 Rotation about the World Frame.....	17
2.3 Representations for General Rotation	19
2.3.1 Euler Angles.....	19
2.3.2 RPY Angles.....	21
2.3.3 Angle/Vector Representation.....	22
2.4 Quaternions	23
2.5 Homogeneous Transformation.....	24
2.6 Transform Equations.....	26
Problems.....	30
3. Robot Kinematics	31
3.1 The Denavit-Hartenberg Convention.....	32
3.1.1 The DH Frame Assignment Procedure	33
3.2 Inverse Kinematics.....	42
3.3 Velocity Kinematics.....	46
3.3.1 Robot Singularities and Manipulability	48
Problems.....	51

4. Trajectory Generation.....	53
4.1 Basic One-Dimensional Scheme.....	53
4.1.1 Cubic Polynomials.....	53
4.1.2 Quintic Polynomials.....	55
4.1.3 Linear Segments with Parabolic Blend.....	57
4.2 Multi-Dimensional Trajectories.....	59
4.3 Multi-segment Trajectories Specified by Via Points.....	60
4.4 Interpolation for 3D Rotation.....	63
4.5 Cartesian Trajectory.....	64
4.6 Trajectory Generation Applied to a Robot.....	66
4.6.1 Effects from Singularity Configurations.....	71
4.6.2 Configuration Change.....	74
4.7 Summary.....	74
Problems.....	76
5. Robot Dynamics and Control.....	77
5.1 Derivation of Robot Equations of Motion.....	77
5.1.1 Euler-Lagrange Equation.....	77
5.1.2 Newton-Euler Recursive Algorithm.....	81
5.2 Dynamic Manipulability.....	88
5.3 Forward Dynamics.....	90
5.4 Independent Joint Dynamics.....	90
5.4.1 Robot Joint Driven by DC Motor.....	90
5.4.2 More Complicated Robot Joint Model.....	92
5.5 Independent Joint Control.....	96
5.5.1 PID Controller.....	96
5.5.2 PID Gain Adjustment.....	98
5.5.3 Effect from Saturation.....	103
5.5.4 PID Tracking with Feedforward Control.....	105
5.6 Cascade Control.....	109
5.6.1 Cascade PID Control of Advanced Joint Model.....	110
5.7 Feedback Control Design.....	115
5.7.1 State Feedback Control.....	117
5.7.2 Output Feedback Control.....	121
5.7.3 H_∞ Control Synthesis.....	122
5.7.4 Cascade H_∞ Control Synthesis.....	138
5.8 Nonlinear Multivariable Control.....	148
5.8.1 PD Control with Gravity Compensation.....	149
5.8.2 Inverse Dynamics.....	156
5.8.3 Adaptive Control.....	163
5.9 Summary.....	172
Problems.....	173

6. Vision-based Control.....	176
6.1 Geometrical Aspects of Image Creation	176
6.1.1 Camera Coordinate Frame	176
6.1.2 Perspective Projection.....	177
6.1.3 Relationship between Image Plane and Sensor Array	178
6.2 Image Enhancement and Processing.....	178
6.3 Vision-based Control	183
6.3.1 Control Configurations	183
6.3.2 Camera Motion and Image Jacobian Matrix.....	184
6.3.3 Proportional Control Scheme.....	188
6.3.4 The Effects of Image Depth	193
6.3.5 Performance of Vision-based Control.....	195
6.4 Summary	197
Problems.....	198
A. RTSX Command Reference.....	199
Bibliography.....	285