



Robot Manipulator Redundancy Resolution

Yunong Zhang and Long Jin

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To our parents and ancestors, as always

Contents

List of Figures	<i>xiii</i>
List of Tables	<i>xxv</i>
Preface	<i>xxvii</i>
Acknowledgments	<i>xxxiii</i>
Acronyms	<i>xxxv</i>

Part I Pseudoinverse-Based ZD Approach 1

1	Redundancy Resolution via Pseudoinverse and ZD Models	3
1.1	Introduction	3
1.2	Problem Formulation and ZD Models	5
1.2.1	Problem Formulation	5
1.2.2	Continuous-Time ZD Model	6
1.2.3	Discrete-Time ZD Models	7
1.2.3.1	Euler-Type DTZD Model with $\dot{j}(t)$ Known	7
1.2.3.2	Euler-Type DTZD Model with $\dot{j}(t)$ Unknown	7
1.2.3.3	Taylor-Type DTZD Models	8
1.3	ZD Applications to Different-Type Robot Manipulators	9
1.3.1	Application to a Five-Link Planar Robot Manipulator	9
1.3.2	Application to a Three-Link Planar Robot Manipulator	12
1.4	Chapter Summary	14

Part II Inverse-Free Simple Approach 15

2	G1 Type Scheme to JVL Inverse Kinematics	17
2.1	Introduction	17
2.2	Preliminaries and Related Work	18
2.3	Scheme Formulation	18
2.4	Computer Simulations	19
2.4.1	Square-Path Tracking Task	19
2.4.2	“Z”-Shaped Path Tracking Task	22
2.5	Physical Experiments	25
2.6	Chapter Summary	26

3	D1G1 Type Scheme to JAL Inverse Kinematics	27
3.1	Introduction	27
3.2	Preliminaries and Related Work	28
3.3	Scheme Formulation	28
3.4	Computer Simulations	29
3.4.1	Rhombus-Path Tracking Task	29
3.4.1.1	Verifications	29
3.4.1.2	Comparisons	30
3.4.2	Triangle-Path Tracking Task	32
3.5	Chapter Summary	36
4	Z1G1 Type Scheme to JAL Inverse Kinematics	37
4.1	Introduction	37
4.2	Problem Formulation and Z1G1 Type Scheme	37
4.3	Computer Simulations	38
4.3.1	Desired Initial Position	38
4.3.1.1	Isosceles-Trapezoid Path Tracking	40
4.3.1.2	Isosceles-Triangle Path Tracking	41
4.3.1.3	Square Path Tracking	42
4.3.2	Nondesired Initial Position	44
4.4	Physical Experiments	45
4.5	Chapter Summary	45
	Part III QP Approach and Unification	47
5	Redundancy Resolution via QP Approach and Unification	49
5.1	Introduction	49
5.2	Robotic Formulation	50
5.3	Handling Joint Physical Limits	52
5.3.1	Joint-Velocity Level	52
5.3.2	Joint-Acceleration Level	52
5.4	Avoiding Obstacles	53
5.5	Various Performance Indices	54
5.5.1	Resolved at Joint-Velocity Level	55
5.5.1.1	MVN scheme	55
5.5.1.2	RMP scheme	55
5.5.1.3	MKE scheme	55
5.5.2	Resolved at Joint-Acceleration Level	55
5.5.2.1	MAN scheme	55
5.5.2.2	MTN scheme	56
5.5.2.3	IIWT scheme	56
5.6	Unified QP Formulation	56
5.7	Online QP Solutions	57
5.7.1	Traditional QP Routines	57

5.7.2	Compact QP Method	57
5.7.3	Dual Neural Network	57
5.7.4	LVI-Aided Primal-Dual Neural Network	57
5.7.5	Numerical Algorithms E47 and 94LVI	59
5.7.5.1	Numerical Algorithm E47	59
5.7.5.2	Numerical Algorithm 94LVI	59
5.8	Computer Simulations	61
5.9	Chapter Summary	66

Part IV Illustrative JVL QP Schemes and Performances 67

6	Varying Joint-Velocity Limits Handled by QP	69
6.1	Introduction	69
6.2	Preliminaries and Problem Formulation	70
6.2.1	Six-DOF Planar Robot System	70
6.2.2	Varying Joint-Velocity Limits	73
6.3	94LVI Assisted QP Solution	76
6.4	Computer Simulations and Physical Experiments	77
6.4.1	Line-Segment Path-Tracking Task	77
6.4.2	Elliptical-Path Tracking Task	85
6.4.3	Simulations with Faster Tasks	87
6.4.3.1	Line-Segment-Path-Tracking Task	87
6.4.3.2	Elliptical-Path-Tracking Task	89
6.5	Chapter Summary	92
7	Feedback-Aided Minimum Joint Motion	95
7.1	Introduction	95
7.2	Preliminaries and Problem Formulation	97
7.2.1	Minimum Joint Motion Performance Index	97
7.2.2	Varying Joint-Velocity Limits	100
7.3	Computer Simulations and Physical Experiments	101
7.3.1	“M”-Shaped Path-Tracking Task	101
7.3.1.1	Simulation Comparisons with Different κ_p	101
7.3.1.2	Simulation Comparisons with Different γ	103
7.3.1.3	Simulative and Experimental Verifications of FAMJM Scheme	105
7.3.2	“P”-Shaped Path Tracking Task	107
7.3.3	Comparisons with Pseudoinverse-Based Approach	108
7.3.3.1	Comparison with Tracking Task of Larger “M”-Shaped Path	110
7.3.3.2	Comparison with Tracking Task of Larger “P”-Shaped Path	112
7.4	Chapter Summary	119
8	QP Based Manipulator State Adjustment	121
8.1	Introduction	121
8.2	Preliminaries and Scheme Formulation	122

- 8.3 QP Solution and Control of Robot Manipulator 124
- 8.4 Computer Simulations and Comparisons 125
 - 8.4.1 State Adjustment without ZIV Constraint 125
 - 8.4.2 State Adjustment with ZIV Constraint 128
- 8.5 Physical Experiments 132
- 8.6 Chapter Summary 136

Part V Self-Motion Planning 137

- 9 QP-Based Self-Motion Planning 139**
 - 9.1 Introduction 139
 - 9.2 Preliminaries and QP Formulation 140
 - 9.2.1 Self-Motion Criterion 140
 - 9.2.2 QP Formulation 141
 - 9.3 LVIAPDNN Assisted QP Solution 141
 - 9.4 PUMA560 Based Computer Simulations 142
 - 9.4.1 From Initial Configuration A to Desired Configuration B 144
 - 9.4.2 From Initial Configuration A to Desired Configuration C 146
 - 9.4.3 From Initial Configuration E to Desired Configuration F 147
 - 9.5 PA10 Based Computer Simulations 152
 - 9.6 Chapter Summary 158
- 10 Pseudoinverse Method and Singularities Discussed 161**
 - 10.1 Introduction 161
 - 10.2 Preliminaries and Scheme Formulation 162
 - 10.2.1 Modified Performance Index for SMP 163
 - 10.2.2 QP-Based SMP Scheme Formulation 163
 - 10.3 LVIAPDNN Assisted QP Solution with Discussion 164
 - 10.4 Computer Simulations 167
 - 10.4.1 Three-Link Redundant Planar Manipulator 168
 - 10.4.1.1 Verifications 168
 - 10.4.1.2 Comparisons 171
 - 10.4.2 PUMA560 Robot Manipulator 172
 - 10.4.3 PA10 Robot Manipulator 176
 - 10.5 Chapter Summary 180
 - Appendix 181
 - Equivalence Analysis in Limit Situation 181
- 11 Self-Motion Planning with ZIV Constraint 183**
 - 11.1 Introduction 183
 - 11.2 Preliminaries and Scheme Formulation 184
 - 11.2.1 Handling Joint Physical Limits 184
 - 11.2.2 QP Reformulation 187
 - 11.2.3 Design of ZIV Constraint 187
 - 11.3 E47 Assisted QP Solution 188
 - 11.4 Computer Simulations and Physical Experiments 189
 - 11.5 Chapter Summary 197

Part VI Manipulability Maximization 199**12 Manipulability-Maximizing SMP Scheme 201**

- 12.1 Introduction 201
- 12.2 Scheme Formulation 202
 - 12.2.1 Derivation of Manipulability Index 202
 - 12.2.2 Handling Physical Limits 203
 - 12.2.3 QP Formulation 203
- 12.3 Computer Simulations and Physical Experiments 204
 - 12.3.1 Computer Simulations 204
 - 12.3.2 Physical Experiments 205
- 12.4 Chapter Summary 209

13 Time-Varying Coefficient Aided MM Scheme 211

- 13.1 Introduction 211
- 13.2 Manipulability-Maximization with Time-Varying Coefficient 212
 - 13.2.1 Nonzero Initial/Final Joint-Velocity Problem 212
 - 13.2.2 Scheme Formulation 213
 - 13.2.3 94LVI Assisted QP Solution 215
- 13.3 Computer Simulations and Physical Experiments 216
 - 13.3.1 Computer Simulations 216
 - 13.3.2 Physical Experiments 224
- 13.4 Chapter Summary 226

Part VII Encoder Feedback and Joystick Control 227**14 QP Based Encoder Feedback Control 229**

- 14.1 Introduction 229
- 14.2 Preliminaries and Scheme Formulation 231
 - 14.2.1 Joint Description 231
 - 14.2.2 OMPFC Scheme 231
- 14.3 Computer Simulations 234
 - 14.3.1 Petal-Shaped Path-Tracking Task 234
 - 14.3.2 Comparative Simulations 238
 - 14.3.2.1 Petal-Shaped Path Tracking Using Another Group of Joint-Angle Limits 238
 - 14.3.2.2 Petal-Shaped Path Tracking via the Method 4 (M4) Algorithm 238
 - 14.3.3 Hexagonal-Path-Tracking Task 239
- 14.4 Physical Experiments 240
- 14.5 Chapter Summary 248

15 QP Based Joystick Control 251

- 15.1 Introduction 251
- 15.2 Preliminaries and Hardware System 251
 - 15.2.1 Velocity-Specified Inverse Kinematics Problem 252
 - 15.2.2 Joystick-Controlled Manipulator Hardware System 252

15.3	Scheme Formulation	253
15.3.1	Cosine-Aided Position-to-Velocity Mapping	253
15.3.2	Real-Time Joystick-Controlled Motion Planning	254
15.4	Computer Simulations and Physical Experiments	254
15.4.1	Movement Toward Four Directions	255
15.4.2	“MVN” Letter Writing	259
15.5	Chapter Summary	259

References 261

Index 277

List of Figures

Figure 1.1	Block diagram of a kinematic-control system for a redundant robot manipulator by combining the MVN scheme (1.1) and ZD model, where $\epsilon = \mathbf{r}_d - \mathbf{f}(\theta)$.	9
Figure 1.2	Geometry of a five-link planar robot manipulator used in simulations.	10
Figure 1.3	Joint-angle and joint-velocity profiles of a five-link planar robot manipulator synthesized by pseudoinverse-based MVN scheme (1.1) aided with TDTZD-U model (1.14).	10
Figure 1.4	(a) Motion process and (b) position error of a five-link planar robot manipulator synthesized by the pseudoinverse-based MVN scheme (1.1) and aided by the TDTZD-U model (1.14).	11
Figure 1.5	Position error of a five-link planar robot manipulator synthesized by a pseudoinverse-based MVN scheme (1.1) aided with the EDTZD-K model (1.9) or Newton iteration (1.15).	12
Figure 1.6	Position errors of a three-link planar robot manipulator synthesized by a pseudoinverse-based MVN scheme (1.1) aided with EDTZD-K model (1.9) with $h = 1.0$.	13
Figure 2.1	(a) Motion process and (b) joint-angle profiles of a five-link redundant robot manipulator tracking the desired square path synthesized by the G1 type scheme (2.8).	20
Figure 2.2	(a) Desired path, actual trajectory, and (b) position error of a five-link redundant robot manipulator tracking square path synthesized by a G1 type scheme (2.8).	20
Figure 2.3	(a) Desired velocity and (b) velocity error of a five-link redundant robot manipulator tracking a square path synthesized by a G1 type scheme (2.8).	21
Figure 2.4	Motion process (a) and joint-angle profiles (b) of six-DOF redundant robot manipulator tracking the desired “Z”-shaped path synthesized by a G1 type scheme (2.8).	22
Figure 2.5	(a) Desired path, actual trajectory, and (b) position error of a six-DOF redundant robot manipulator tracking a “Z”-shaped path synthesized by a G1 type scheme (2.8).	23

Figure 2.6	(a) Desired velocity and (b) velocity error of a six-DOF redundant robot manipulator tracking a “Z”-shaped path synthesized by a G1 type scheme (2.8).	23
Figure 2.7	Hardware system (a) of six-DOF planar redundant robot manipulator with its structure platform (b). <i>Source:</i> Zhang et al. 2015. Reproduced from Y. Zhang, L. He, J. Ma et al., Inverse-free scheme of G1 type to velocity-level inverse kinematics of redundant robot manipulators, Figure 3, Proceedings of the Twelfth International Symposium on Neural Networks, pp. 99-108, 2015. © Springer-Verlag 2015. With kind permission of Springer-Verlag (License Number 3978560065761).	24
Figure 2.8	“Z”-shaped-path-tracking experiment of six-DOF redundant robot manipulator synthesized by G1 type scheme (2.8) at joint-velocity level. Reproduced from Y. Zhang, L. He, J. Ma et al, Inverse-free scheme of G1 type to velocity-level inverse kinematics of redundant robot manipulators, Figure 4, Proceedings of the Twelfth International Symposium on Neural Networks, pp. 99-108, 2015. © Springer-Verlag 2015. With kind permission of Springer-Verlag (License Number 3978560065761).	25
Figure 3.1	(a) Motion process, (b) desired path, and actual trajectory of a three-link redundant robot manipulator tracking a rhombus path synthesized by the D1G1 scheme (3.7) with $\lambda = 10^4$.	30
Figure 3.2	Joint-angle profiles (a) and position error (b) of a three-link redundant robot manipulator tracking a rhombus path synthesized by the D1G1 scheme (3.7) with $\lambda = 10^4$.	31
Figure 3.3	Joint-velocity profiles (a) and velocity error (b) of a three-link redundant robot manipulator tracking a rhombus path synthesized by the D1G1 scheme (3.7) with $\lambda = 10^4$.	32
Figure 3.4	(a) Joint-acceleration profiles and (b) acceleration error of a three-link redundant robot manipulator tracking a rhombus path synthesized by the D1G1 scheme (3.7) with $\lambda = 10^4$.	33
Figure 3.5	Position errors in rhombus-path-tracking task of a three-link robot manipulator synthesized by (a) pseudoinverse solution (3.4) and (b) inverse-free D1G1 scheme (3.7) with $\lambda = 10^5$.	34
Figure 3.6	(a) Motion process and (b) joint-angle profiles of a three-link redundant robot manipulator tracking a desired triangle path synthesized by a D1G1 scheme (3.7) with $\lambda = 10^5$.	35
Figure 3.7	Position errors in triangle-path-tracking task of the three-link robot manipulator synthesized by (a) pseudoinverse solution (3.4) and (b) inverse-free D1G1 scheme (3.7) with $\lambda = 10^5$.	36
Figure 4.1	(a) Motion process and (b) joint-angle profiles of a three-link planar robot manipulator tracking a desired isosceles-trapezoid path synthesized by the Z1G1 type scheme (4.5).	39

Figure 4.2	(a) Joint-velocity profiles and (b) joint-acceleration profiles of three-link planar robot manipulator tracking isosceles-trapezoid path synthesized by Z1G1 type scheme (4.5).	40
Figure 4.3	(a) Motion process and (b) joint-angle profiles of a four-link planar robot manipulator tracking a desired isosceles-triangle path synthesized by the Z1G1 type scheme (4.5).	41
Figure 4.4	(a) Joint-velocity profiles and (b) joint-acceleration profiles of a four-link planar robot manipulator tracking an isosceles-triangle path synthesized by the Z1G1 type scheme (4.5).	42
Figure 4.5	Simulation results of a three-link planar robot manipulator tracking an isosceles-trapezoid path synthesized by the Z1G1 type scheme (4.5) with an initial end-effector position not on the desired path.	43
Figure 4.6	“V”-shaped-path-tracking experiment of a six-DOF redundant robot manipulator synthesized by the Z1G1 type scheme (4.5) at joint-acceleration level. <i>Source</i> : Wang 2015. Reproduced with permission of IEEE.	44
Figure 5.1	Contradicting situations in equality-based collision-free formulation.	54
Figure 5.2	QP-based approach to redundancy resolution and torque control.	58
Figure 5.3	PUMA560 transients synthesized by a QP-based MTN scheme.	62
Figure 5.4	PUMA560 transients synthesized by a QP-based MKE scheme.	63
Figure 5.5	Comparison of (a) conventional and (b) presented MTN schemes.	64
Figure 5.6	Joint-torque profiles synthesized by other QP-based resolution schemes of (a) IIWT and (b) MAN.	65
Figure 5.7	Joint-torque profiles synthesized by other QP-based resolution schemes of (a) MKE and (b) MVN.	65
Figure 6.1	(a) Hardware system and (b) model of a six-DOF planar robot manipulator. <i>Source</i> : Zhang 2013. Reproduced with permission of IEEE.	71
Figure 6.2	Local configuration of a six-DOF planar robot manipulator. <i>Source</i> : Zhang 2013. Reproduced with permission of IEEE.	72
Figure 6.3	Relationship between (a) $\dot{\theta}_1^\pm$ and θ_1 as well as (b) the relationship between $\dot{\theta}_2^\pm$ and θ_2 .	74
Figure 6.4	Relationship between (a) $\dot{\theta}_3^\pm$ and θ_3 as well as (b) the relationship between $\dot{\theta}_4^\pm$ and θ_4 .	75
Figure 6.5	Relationship between (a) $\dot{\theta}_5^\pm$ and θ_5 as well as (b) the relationship between $\dot{\theta}_6^\pm$ and θ_6 .	76
Figure 6.6	Desired line-segment path to be tracked by the end-effector of a six-DOF planar robot manipulator.	78

- Figure 6.7** Snapshots for an actual task execution of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when a robot end-effector tracks a line-segment path. Reproduced from Z. Zhang, and Y. Zhang, Variable Joint-Velocity Limits of Redundant Robot Manipulators Handled by Quadratic Programming, Figure 5, IEEE/ASME Trans. Mechatronics, Vol. 18, No. 2, pp. 674-686, 2013. *Source:* Zhang 2013. Reproduced with permission of IEEE. 79
- Figure 6.8** Actual end-effector trajectory generated by a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme. *Source:* Zhang 2013. Reproduced with permission of IEEE. 79
- Figure 6.9** Simulated six-DOF planar robot manipulator and its joints' trajectories synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks a line-segment path. 80
- Figure 6.10** (a) PPS_1 and (b) PPS_2 transmitted to joint motors when the end-effector tracks a line-segment path. 80
- Figure 6.11** (a) PPS_3 and (b) PPS_4 transmitted to joint motors when the end-effector tracks a line-segment path. 81
- Figure 6.12** (a) PPS_5 and (b) PPS_6 transmitted to joint motors when the end-effector tracks a line-segment path. 82
- Figure 6.13** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks a line-segment path. 83
- Figure 6.14** End-effector position error of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks a line-segment path. 84
- Figure 6.15** Snapshots for actual task execution of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks an elliptical path. *Source:* Zhang 2013. Reproduced with permission of IEEE. 85
- Figure 6.16** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks an elliptical path. 86
- Figure 6.17** End-effector position error of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when the robot end-effector tracks an elliptical path. 87
- Figure 6.18** Joint-velocity profiles of (a) $\dot{\theta}_1$ and (b) $\dot{\theta}_2$ of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when its end-effector tracks a line-segment path much faster. 88
- Figure 6.19** Joint-velocity profiles of (a) $\dot{\theta}_3$ and (b) $\dot{\theta}_4$ of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when its end-effector tracks a line-segment path much faster. 89

- Figure 6.20** Joint-velocity profiles of (a) $\dot{\theta}_5$ and (b) $\dot{\theta}_6$ of a six-DOF planar robot manipulator synthesized by a the VJVL-constrained MVN scheme when its end-effector tracks a line-segment path much faster. 90
- Figure 6.21** End-effector position error of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when its end-effector tracks a line-segment path much faster. 91
- Figure 6.22** Joint-velocity profiles of a robot synthesized by a VJVL-constrained MVN scheme when its end-effector tracks an elliptical path much faster, which includes a profile of joint velocity $\dot{\theta}_4$ within and sometimes reaching limits of ξ_4^\pm . 91
- Figure 6.23** End-effector position error of a six-DOF planar robot manipulator synthesized by a VJVL-constrained MVN scheme when its end-effector tracks an elliptical path much faster. 92
- Figure 6.24** Iteration number and computing time of a numerical algorithm 94LVI (6.17) per sampling period in a much faster elliptical-path tracking task. 92
- Figure 7.1** (a) Desired “M”-shaped path and (b) motion process of a six-DOF planar robot manipulator synthesized by a FAMJM scheme (7.23)–(7.25). 102
- Figure 7.2** Maximum error variation tendency of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) when κ_p increases from 0 to 100 during “M”-shaped-path-tracking execution. 104
- Figure 7.3** Joint displacement variation tendency of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks an “M”-shaped path. 104
- Figure 7.4** Snapshots for actual task execution of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks an “M”-shaped path. *Source:* Zhang 2013. Reproduced with permission of permission of TCCT (License Number 201611080923). 106
- Figure 7.5** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) with $\gamma = 4$ and $\kappa_p = 6$ when a robot end-effector tracks an “M”-shaped path. 106
- Figure 7.6** (a) Desired path, end-effector trajectory, and (b) position error for actual task execution of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) with $\gamma = 4$ and $\kappa_p = 6$ when a robot end-effector tracks an “M”-shaped path. 107
- Figure 7.7** Snapshots of the actual task execution of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a “P”-shaped path. *Source:* Zhang 2013. Reproduced with permission of permission of TCCT (License Number 201611080923). 109

Figure 7.8	Joint-angle profiles of (a) θ_1 and (b) θ_2 synthesized by PBMJM scheme (7.27) when a robot end-effector tracks a larger “M”-shaped path.	110
Figure 7.9	Joint-angle profiles of (a) θ_3 and (b) θ_4 synthesized by PBMJM scheme (7.27) when a robot end-effector tracks a larger “M”-shaped path.	111
Figure 7.10	Joint-angle profiles of (a) θ_5 and (b) θ_6 synthesized by PBMJM scheme (7.27) when a robot end-effector tracks a larger “M”-shaped path.	112
Figure 7.11	Joint-angle profiles of (a) θ_1 and (b) θ_2 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “M”-shaped path.	113
Figure 7.12	Joint-angle profiles of (a) θ_3 and (b) θ_4 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “M”-shaped path.	114
Figure 7.13	Joint-angle profiles of (a) θ_5 and (b) θ_6 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “M”-shaped path.	114
Figure 7.14	Joint-angle profiles of (a) θ_1 and (b) θ_2 synthesized by PBMJM scheme (7.27) when robot end-effector tracks a larger “P”-shaped path.	115
Figure 7.15	Joint-angle profiles of (a) θ_3 and (b) θ_4 synthesized by PBMJM scheme (7.27) when a robot end-effector tracks a larger “P”-shaped path.	116
Figure 7.16	Joint-angle profiles of (a) θ_5 and (b) θ_6 synthesized by PBMJM scheme (7.27) when a robot end-effector tracks a larger “P”-shaped path.	116
Figure 7.17	Joint-angle profiles of (a) θ_1 and (b) θ_2 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “P”-shaped path.	117
Figure 7.18	Joint-angle profiles of (a) θ_3 and (b) θ_4 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “P”-shaped path.	118
Figure 7.19	Joint-angle profiles of (a) θ_5 and (b) θ_6 synthesized by FAMJM scheme (7.23)–(7.25) when a robot end-effector tracks a larger “P”-shaped path.	118
Figure 8.1	(a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) without imposing a zero-initial-velocity constraint and with parameters $\gamma = 1$ and $T = 30$ s.	126
Figure 8.2	(a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) without imposing a zero-initial-velocity constraint and with parameters $\gamma = 2$ and $T = 10$ s.	127

- Figure 8.3** (a) Motion process and (b) trajectories of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) with a zero-initial-velocity constraint imposed (i.e., QP (8.13)–(8.14)) and with $\gamma = 1$ and $T = 10$ s. 128
- Figure 8.4** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) with zero-initial-velocity constraint imposed (i.e., QP (8.13)–(8.14)) and with $\gamma = 1$ and $T = 30$ s. 129
- Figure 8.5** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) with a zero-initial-velocity constraint imposed (i.e., QP (8.13)–(8.14)) and with $\gamma = 1$ and $T = 10$ s. 130
- Figure 8.6** (a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by state-adjustment scheme (8.1)–(8.3) with a zero-initial-velocity constraint imposed (i.e., QP (8.13)–(8.14)) and with $\gamma = 2$ and $T = 10$ s. 131
- Figure 8.7** (a) PPS_1 and (b) PPS_2 for controlling a six-DOF planar robot manipulator. 133
- Figure 8.8** (a) PPS_3 and (b) PPS_4 for controlling a six-DOF planar robot manipulator. 134
- Figure 8.9** (a) PPS_5 and (b) PPS_6 for controlling a six-DOF planar robot manipulator. 135
- Figure 8.10** Motion transients of a physical six-DOF planar robot manipulator from initial state $\theta(0)$ to desired state θ_d , which is synthesized by state-adjustment scheme (8.13)–(8.14) with $T = 10$ s. *Source:* Li 2012. Reproduced with permission of Cambridge University Press. 136
- Figure 9.1** Three-dimensional motion trajectories of a PUMA560 robot manipulator performing self-motion from configurations A to B with $\lambda = 4$. 144
- Figure 9.2** (a) Joint-angle and (b) joint-velocity profiles of PUMA560 robot manipulator performing self-motion from configurations A to B with $\lambda = 4$. 145
- Figure 9.3** Three-dimensional motion trajectories of a PUMA560 robot manipulator performing self-motion from configurations A to C with $\lambda = 4$. 147
- Figure 9.4** (a) Joint-angle and (b) joint-velocity profiles of a PUMA560 robot manipulator performing self-motion from configurations A to C with $\lambda = 4$. 148
- Figure 9.5** (a) Three-dimensional motion trajectories and (b) maximal end-effector position error of a PUMA560 robot manipulator from configurations E to F with $\lambda = 4$. 149
- Figure 9.6** (a) Joint-angle and (b) joint-velocity profiles of a PUMA560 robot manipulator from configurations E to F with $\lambda = 4$. 150

Figure 9.7	(a) Joint-angle and (b) joint-velocity profiles of a PUMA560 robot manipulator performing self-motion from configurations E to F with $\lambda = 20$.	152
Figure 9.8	Three-dimensional motion trajectories of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d without moving the end-effector) with $\lambda = 3$.	153
Figure 9.9	(a) Joint-angle and (b) joint-velocity profiles of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d without moving end-effector) with $\lambda = 3$.	154
Figure 9.10	Resultant position error of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d theoretically without moving the end-effector) with $\lambda = 3$.	155
Figure 9.11	(a) Joint-angle and (b) joint-velocity profiles of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d without moving the end-effector) with $\lambda = 30$.	156
Figure 9.12	Three-dimensional motion trajectories of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d without moving the end-effector) with $\lambda = 30$.	157
Figure 9.13	Resultant position error of a PA10 manipulator performing self-motion (from $\theta(0)$ to θ_d theoretically without moving the end-effector) with $\lambda = 30$.	158
Figure 10.1	Block diagram of dynamic configuration of SMP for a redundant manipulator.	162
Figure 10.2	LVIAPDNN structure corresponding to dynamic equation (10.9).	166
Figure 10.3	Examples of three initial states of self-motion for a three-link redundant planar manipulator.	167
Figure 10.4	(a) Motion trajectories and (b) end-effector position error of a three-link robot performing self-motion with $\lambda = 2$.	168
Figure 10.5	(a) Joint-angle and (b) joint-velocity profiles of a three-link robot performing self-motion with $\lambda = 2$.	169
Figure 10.6	(a) Joint-velocity profiles and (b) motion trajectories of a three-link planar robot performing self-motion synthesized by the pseudoinverse-based method (10.12) with $\lambda = 8$ and without considering constraint (10.8).	171
Figure 10.7	(a) Joint-velocity profiles and (b) motion trajectories of a three-link planar robot performing self-motion synthesized by the pseudoinverse-based method (10.12) with $\lambda = 8$ and with constraint (10.8) imposed.	172
Figure 10.8	(a) Joint-velocity profiles and (b) motion trajectories of a three-link planar robot performing self-motion synthesized by LVIAPDNN solver (10.9) with $\lambda = 8$ and with constraint (10.8) imposed as well.	173
Figure 10.9	(a) Motion trajectories and (b) end-effector position error of PUMA560 robot performing self-motion.	174

- Figure 10.10** (a) Joint-angle and (b) joint-velocity profiles of a PUMA560 robot performing self-motion with $\lambda = 4$. 175
- Figure 10.11** End-effector position errors of PUMA560 robot performing self-motion synthesized by LVIAPDNN solver (10.9) with different values of γ (i.e., (a) $\gamma = 10^2$ and (b) $\gamma = 10^4$). 176
- Figure 10.12** End-effector position errors of a PUMA560 robot performing self-motion synthesized by LVIAPDNN solver (10.9) with different values of γ (i.e., (a) $\gamma = 10^6$ and (b) $\gamma = 10^8$). 177
- Figure 10.13** (a) Motion trajectories and (b) end-effector position error of a PA10 robot performing self-motion with $\lambda = 4$. 178
- Figure 10.14** (a) Joint-angle and (b) joint-velocity profiles of a PA10 robot performing self-motion with $\lambda = 4$. 179
- Figure 10.15** (a) Motion trajectories and (b) θ_d -proximity of a PA10 robot performing self-motion with $\mathbf{f}(\theta_d) \neq \mathbf{f}(\theta(0))$. 180
- Figure 11.1** Safety device and limit-position indicators of a six-DOF planar robot manipulator. *Source*: Li 2012. Reproduced with permission of Emerald Group Publishing Limited. 185
- Figure 11.2** Limits analysis of a six-DOF planar robot manipulator. 186
- Figure 11.3** Block chart of zero-initial-velocity self-motion planning and control of a six-DOF planar robot manipulator. 188
- Figure 11.4** Profiles of joint-velocity limits $\dot{\theta}_i^\pm$, velocity-level angle-converted bounds $\mu_v(\xi_i^\pm - \theta_i)$ and corresponding bounds η_i^\pm with $i \in \{1, 2, 3\}$ of a six-DOF planar robot manipulator synthesized by QP (11.7)–(11.9) without imposing a zero-initial-velocity constraint. 190
- Figure 11.5** Profiles of joint-velocity limits $\dot{\theta}_i^\pm$, velocity-level angle-converted bounds $\mu_v(\xi_i^\pm - \theta_i)$ and corresponding bounds η_i^\pm with $i \in \{4, 5, 6\}$ of a six-DOF planar robot manipulator synthesized by QP (11.7)–(11.9) without imposing a zero-initial-velocity constraint. 191
- Figure 11.6** Profiles of joint-velocity limits $\dot{\theta}_i^\pm$, velocity-level angle-converted bounds $\mu_v(\xi_i^\pm - \theta_i)$ and final corresponding bounds x_i^\pm with $i \in \{1, 2, 3\}$ of a six-DOF planar robot manipulator synthesized by QP (11.10)–(11.12) with a zero-initial-velocity constraint imposed. 192
- Figure 11.7** Profiles of joint-velocity limits $\dot{\theta}_i^\pm$, velocity-level angle-converted bounds $\mu_v(\xi_i^\pm - \theta_i)$, and final corresponding bounds x_i^\pm with $i \in \{4, 5, 6\}$ of a six-DOF planar robot manipulator synthesized by QP (11.10)–(11.12) with a zero-initial-velocity constraint imposed. 193
- Figure 11.8** Joint-angle profiles of a six-DOF planar robot manipulator synthesized by self-motion schemes. 194
- Figure 11.9** (a) PPS₁, (b) PPS₂, and (c) PPS₃ for controlling a six-DOF planar robot manipulator. 195
- Figure 11.10** (a) PPS₄, (b) PPS₅, and (c) PPS₆ for controlling a six-DOF planar robot manipulator. 196

Figure 11.11	Self-motion task execution of a manipulator synthesized by the self-motion scheme (11.10)–(11.12).	197
Figure 12.1	Manipulability measures $M(\theta) = \sqrt{\det(JJ^T)}$ synthesized by MMSMP scheme (12.2)–(12.5) and SMMVA scheme [203].	205
Figure 12.2	(a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by the MMSMP scheme (12.2)–(12.5).	206
Figure 12.3	Manipulability measures $M(\theta)$ of a six-DOF planar robot manipulator synthesized by the (a) MMSMP and (b) SMMVA schemes.	207
Figure 12.4	Self-motion task execution of a six-DOF planar robot manipulator synthesized by the MMSMP scheme (12.2)–(12.5). <i>Source</i> : IEEE 2012. Reproduced with permission of IEEE.	208
Figure 13.1	(a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator synthesized by a manipulability-maximizing scheme with a constant coefficient $p(t) = 1$.	217
Figure 13.2	(a) Motion trajectories as well as (b) end-effector path and trajectory of the end-effector of a six-DOF planar robot manipulator tracking an “R” path synthesized by time-varying coefficient aided manipulability-maximizing scheme (i.e., $p(t) = 2 \sin(\pi t/T)$).	218
Figure 13.3	(a) Joint-angle and (b) joint-velocity profiles of a six-DOF planar robot manipulator tracking an “R” path synthesized by a time-varying coefficient aided manipulability-maximizing scheme (i.e., $p(t) = 2 \sin(\pi t/T)$).	219
Figure 13.4	Comparison about manipulability index $w = \det(JJ^T)$ synthesized by schemes with $p(t) = 2 \sin(\pi t/T)$, $p(t) = 0$ (i.e., an MVN scheme) and $p(t) = 1$.	220
Figure 13.5	Joint-angle profiles (a) θ_1 and (b) θ_2 of corresponding limits of a six-DOF planar robot manipulator tracking an “R” path synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$.	220
Figure 13.6	Joint-angle profiles (a) θ_3 and (b) θ_4 of corresponding limits of a six-DOF planar robot manipulator tracking an “R” path synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$.	221
Figure 13.7	Joint-angle profiles (a) θ_5 and (b) θ_6 of corresponding limits of a six-DOF planar robot manipulator tracking an “R” path synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$.	222
Figure 13.8	Joint-velocity profiles (a) $\dot{\theta}_1$ and (b) $\dot{\theta}_2$ of corresponding limits and bounds of a six-DOF planar robot manipulator tracking an “R” path synthesized by a TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$.	222
Figure 13.9	Joint-velocity profiles (a) $\dot{\theta}_3$ and (b) $\dot{\theta}_4$ of corresponding limits and bounds of a six-DOF planar robot manipulator tracking an “R” path synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$.	223

- Figure 13.10** Joint-velocity profiles (a) $\dot{\theta}_5$ and (b) $\dot{\theta}_6$ of corresponding limits and bounds of a six-DOF planar robot manipulator tracking an “R” path synthesized by a TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$. 224
- Figure 13.11** Snapshots for actual end-effector task execution of a six-DOF planar robot manipulator tracking an “R” path synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$. *Source:* Zhang 2013. Reproduced with permission of John Wiley & Sons. 225
- Figure 13.12** (a) Top-view measurement result of “R” trajectory and (b) positioning error of robot end-effector synthesized by TVCMM scheme with $p(t) = 2 \sin(\pi t/T)$. *Source:* Zhang 2013. Reproduced with permission of John Wiley & Sons. 225
- Figure 14.1** Joint structure of Joint 2 through Joint 6. *Source:* Zhang 2013. Reproduced with permission of Elsevier. 232
- Figure 14.2** (a) Motion trajectories, as well as (b) desired path and actual trajectory of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by an OMPFC scheme with L1. 235
- Figure 14.3** (a) Position error and (b) joint-velocity profiles of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by a OMPFC scheme with L1. 236
- Figure 14.4** (a) Joint-angle profiles and (b) joint-angle-limit constraint (θ_2^-) of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by a OMPFC scheme with L1. 236
- Figure 14.5** (a) Iteration numbers and (b) running times of numerical algorithm 94LVI for a six-DOF planar robot manipulator tracking a petal-shaped path. 237
- Figure 14.6** (a) Motion trajectories and (b) position error of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by OMPFC scheme with L2. 239
- Figure 14.7** (a) Joint-angle-limit constraint (θ_2^-) and (b) running times of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by a OMPFC scheme with L2. 240
- Figure 14.8** (a) Motion trajectories and (b) position error of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by a scheme equipped with the M4 algorithm and L1. 241
- Figure 14.9** (a) Iteration numbers and (b) running times of a six-DOF planar robot manipulator tracking a petal-shaped path synthesized by a scheme equipped with the M4 algorithm and L1. 242
- Figure 14.10** Simulation results of a six-DOF planar robot manipulator tracking a hexagonal path synthesized by an OMPFC scheme with L1. 242
- Figure 14.11** Experimental end-effector position error synthesized by a OMPFC scheme with $\kappa_p = 0$ for tracking a petal-shaped path. 243

- Figure 14.12** Snapshots for actual petal-shaped-path-tracking task execution of manipulator synthesized by OMPFC scheme with $\kappa_p = 6$. *Source:* Zhang 2013. Reproduced with permission of Elsevier. 244
- Figure 14.13** Top-view measurement for actual task execution results synthesized by OMPFC scheme with $\kappa_p = 6$. *Source:* Zhang 2013. Reproduced with permission of Elsevier. 244
- Figure 14.14** (a) Experimental end-effector trajectory and (b) position error synthesized by an OMPFC scheme with $\kappa_p = 6$ for tracking a petal-shaped path. 245
- Figure 14.15** Comparison between actual-measured (with subscript $_{ia}$) and simulated (with subscript $_{is}$) θ_i synthesized by an OMPFC scheme with $\kappa_p = 6$ for tracking a petal-shaped path ($i \in \{1, 2, 3\}$). 246
- Figure 14.16** Comparison between actual-measured (with subscript $_{ia}$) and simulated (with subscript $_{is}$) θ_i synthesized by an OMPFC scheme with $\kappa_p = 6$ for tracking a petal-shaped path ($i \in \{4, 5, 6\}$). 247
- Figure 14.17** (a) Experimental end-effector trajectory and (b) position error synthesized by an OMPFC scheme with $\kappa_p = 6$ for tracking a hexagonal path. 248
- Figure 15.1** Conceptual block diagram of a joystick-controlled robot system. 252
- Figure 15.2** Joystick. *Source:* IEEE 2011. Reproduced with permission of IEEE. 252
- Figure 15.3** Block diagram of cosine-aided position-to-velocity mapping. 254
- Figure 15.4** Computing times used by numerical algorithm 94LVI for redundancy resolution in simulations of (a) forward and (b) backward movement. 255
- Figure 15.5** Computing times used by numerical algorithm 94LVI for redundancy resolution in simulations of (a) leftward and (b) rightward movement. 256
- Figure 15.6** Computing times used by numerical algorithm 94LVI for redundancy resolution in simulations of (a) upper-rightward and (b) lower-rightward movement. 257
- Figure 15.7** Directional manipulation of joystick. *Source:* IEEE 2011. Reproduced with permission of IEEE. 258
- Figure 15.8** Actual end-effector trajectories corresponding to Figure 15.7. *Source:* Zhang 2011. Reproduced with permission of IEEE. 258
- Figure 15.9** Manipulation of joystick for writing “MVN”. *Source:* IEEE 2011. Reproduced with permission of IEEE. 259
- Figure 15.10** Actual end-effector trajectories corresponding to Figure 15.9. *Source:* Zhang 2011. Reproduced with permission of IEEE. 260

List of Tables

Table 3.1	Position and velocity errors of a three-link robot manipulator's end-effector tracking rhombus and triangle paths synthesized by a inverse-free DIG1 scheme (3.7).	34
Table 4.1	Maximum position, velocity, and acceleration errors when three planar robot manipulators track desired paths synthesized by ZIG1 type scheme (4.5).	39
Table 6.1	Parameters of a six-DOF planar robot manipulator hardware system.	72
Table 6.2	Maximum and average position errors (m) of a six-DOF planar robot manipulator's end-effector for different paths tracked.	84
Table 6.3	Iteration number and computing time within each sampling period when a robot tracks a line-segment or an elliptical path.	84
Table 7.1	Actual joint-angle limits used in this chapter of six-DOF planar robot manipulator.	102
Table 7.2	Maximum errors of a six-DOF planar robot manipulator synthesized by FAMJM scheme (7.23)–(7.25) when κ_p increases from 0 to 100 during task execution of “M”-shaped-path tracking.	103
Table 8.1	Joint-angle values with $\gamma = 1$ and $T = 30$ s at different time t instants.	126
Table 8.2	Joint-angle errors $\{ e_i(T) \}_{i=1}^6$ of state-adjustment task for different γ and T .	129
Table 9.1	Initial configurations and desired configurations (rad) of PUMA560 robot manipulator involved in the simulations.	143
Table 9.2	Joint values and errors of PUMA560 robot manipulator before and after self-motion from configurations A to B (rad).	146
Table 9.3	Joint-angle values and errors of PUMA560 robot manipulator before and after self-motion from configurations A to C (rad).	149
Table 9.4	Joint-angle values and errors of PUMA560 robot manipulator before and after self-motion from configurations E to F (rad).	151
Table 9.5	Joint-angle limits and joint-velocity limits used in this chapter for a PA10 manipulator.	153

Table 9.6	Joint-angle values and errors of a PA10 manipulator before and after self-motion with $\lambda = 3$ (rad).	155
Table 9.7	Joint-angle values and errors of a PA10 manipulator before and after self-motion with $\lambda = 30$ (rad).	158
Table 10.1	Joint values and errors (rad) of three-link robot before and after self-motion with $\lambda = 2$.	170
Table 10.2	Final joint values and errors (rad) of a three-link robot before and after self-motion with $\lambda = 4$.	170
Table 10.3	Final joint values and errors (rad) of a three-link robot before and after self-motion with $\lambda = 8$.	170
Table 10.4	Joint values and errors (rad) of a PUMA560 robot before and after self-motion with $\lambda = 4$.	174
Table 10.5	Joint values and errors (rad) of a PA10 robot before and after self-motion with $\lambda = 4$.	178
Table 14.1	Motor parameters of a six-DOF planar robot manipulator.	232

Preface

In recent decades, robotics has attracted considerable attention in scientific research and engineering applications. Much effort has been contributed to robotics and different types of robots have thus been developed and investigated. Among these robots, redundant robot manipulators have played a more and more important role in numerous fields of engineering applications, and they have been widely applied in industrial automation for performing repetitive dull work, such as welding, painting, and assembly. For a redundant robot manipulator, it possesses more degrees-of-freedom (DOF) than the minimum number required to perform a given end-effector primary task. One important issue in operating such robotic systems, redundancy resolution, has been widely studied, which is related to the motion planning and control of redundant manipulators. That is, given the desired Cartesian paths of the end effector, the corresponding joint trajectories need to be obtained online or in real-time t . Various redundancy-resolution schemes have thus been developed and investigated for the motion planning and control of redundant robot manipulators. By resolving the redundancy properly (or say, by using a specific redundancy-resolution scheme), redundant robot manipulators can avoid joint physical limits, while conducting the given end-effector primary path-tracking task.

In general, the redundancy-resolution problem can be solved at the joint-velocity level or at the joint-acceleration level, resulting in the corresponding velocity-level and acceleration-level redundancy-resolution schemes. In this book, focusing on redundancy resolution, we present and investigate different methods and schemes for the motion planning and control of redundant robot manipulators. Specifically, in view of the fact that the Jacobian matrix of a robot manipulator is actually varying with time during the motion-task execution, the problem of time-varying matrix pseudoinversion, as a new issue, is involved in the pseudoinverse-based scheme formulation. By computing the time-varying pseudoinverse of the Jacobian matrix (of the robot manipulator), discrete-time zeroing dynamics (ZD) models, as a new approach to the time-varying Jacobian matrix pseudoinversion, are applied to the redundant-manipulator kinematic control. Then, considering that calculating the inverse of Jacobian matrix is less efficient, three types of inverse-free simple solution based on the gradient dynamics (GD) method and ZD method, are thus presented and investigated to avoid the Jacobian inversion. Recent progress in our 16-year study shows the advantages of unifying the treatment of various schemes of manipulators' redundancy resolution. We recall some fundamental techniques for such a unification and then specify it in full details based on quadratic programming (QP) and its online

solutions. Such a QP formulation is general in the sense that it incorporates equality, inequality, and bound constraints, simultaneously. This QP formulation covers the online avoidance of joint physical limits and environmental obstacles, as well as the optimization of various performance indices. Every term is endowed with clear physical meaning and utility. Computer-simulation results based on various robotic models show the effectiveness of the presented methods and schemes. For substantiating the physical realizability, some of these methods and schemes are applied to an actual six-DOF planar robot manipulator.

The idea for this book was conceived during the research discussion in the laboratory and at international scientific meetings. Most of the materials of this book are derived from the authors' papers published in journals and proceedings of international conferences. In fact, in recent decades, the field of robotics has undergone the phases of exponential growth, generating many new theoretical concepts and applications (including the authors' ones). Our first priority is thus to cover each central topic in enough details to make the material clear and coherent; in other words, each part (and even each chapter) is written in a relatively self-contained manner.

This book contains 15 chapters that are classified into the following seven parts.

Part I: Pseudoinverse-Based ZD Approach (Chapter 1);

Part II: Inverse-Free Simple Approach (Chapter 2 through Chapter 4);

Part III: QP Approach and Unification (Chapter 5);

Part IV: Illustrative Velocity-Level QP Schemes and Performances (Chapter 6 through Chapter 8);

Part V: Self-Motion Planning (Chapter 9 through Chapter 11);

Part VI: Manipulability Maximization (Chapter 12 and Chapter 13);

Part VII: Encoder Feedback and Joystick Control (Chapter 14 and Chapter 15).

Chapter 1 – This chapter presents and investigates the applications of discrete-time ZD models to the kinematic control of redundant robot manipulators via time-varying matrix pseudoinversion. That is, by computing the time-varying pseudoinverse of the Jacobian matrix (of the robot manipulator), the resultant ZD models are applied to the redundant-manipulator kinematic control. Computer-simulation results based on two robot manipulators further illustrate the effectiveness of the presented ZD models for time-varying matrix pseudoinversion applied to the redundancy resolution of robot manipulators.

Chapter 2 – In this chapter, based on GD method, an inverse-free scheme is presented at the joint-velocity level to avoid calculating the inverse of Jacobian matrix. The scheme is called a G1 type as it uses GD once. In addition, two path tracking simulations based on five-link and six-DOF redundant robot manipulators illustrate the efficiency and the accuracy of the presented scheme. What is more, the physical realizability of G1 type scheme is also verified by the physical experiments based on the six-DOF planar redundant robot manipulator hardware system.

Chapter 3 – In this chapter, another inverse-free simple solution based on GD method, named the D1G1 scheme, is presented at the joint-acceleration level for solving the inverse kinematics problem of redundant robot manipulators. Furthermore, simulation results based on a three-link redundant robot manipulator substantiate the effectiveness and accuracy of the presented inverse-free D1G1 scheme.