

References

1. J. Angeles, *Rational Kinematics* (Springer, New York, 1988)
2. J. Angeles, *Int. J. Robot. Res.* **11**(3), 196 (1992)
3. J. Angeles, *Fundamentals of Robotic Mechanical Systems*, 3rd edn. (Springer, New York, 2007)
4. J. Babič, J. Lenarčič, in *On Advances in Robot Kinematics*, ed. by J. Lenarčič, C. Galletti (Kluwer Academic Publishers, Dordrecht, 2004), pp. 155–162
5. J. Babič, L. Bokman, D. Omrčen, J. Lenarčič, F. Park, *J. Mech. Robot.* **1**, 1 (2009)
6. T. Bajd, M. Mihelj, J. Lenarčič, A. Stanovnik, M. Munih, *Robotics* (Springer, Dordrecht, 2010)
7. D.R. Baker, C.W. Wampler, *Int. J. Robot. Res.* **7**(2), 3 (1988)
8. R.S. Ball, *A Treatise on the Theory of Screws* (Cambridge University Press, Cambridge, 1900)
9. Z. Balorda, T. Bajd, *IEEE Trans. Robot. Autom.* **10**(4), 535 (1994)
10. O. Bottema, B. Roth, *Theoretical Kinematics* (Dover, New York, 1979/1990)
11. R.C. Brost, *Int. J. Robot. Res.* **7**(1), 3 (1988)
12. M. Ceccarelli, A. Vinciguerra, *Int. J. Robot. Res.* **14**(2), 152 (1995)
13. G.S. Cirikjian, J.W. Burdick, *IEEE Trans. Robot. Autom.* **10**(3), 343 (1994)
14. R. Clavel, in *Proceedings 18th International Symposium on Industrial Robots*, Sydney, Australia (1988), pp. 91–100
15. J.J. Craig, *Introduction to Robotics: Mechanics and Control*, 3rd edn. (Pearson/Prentice-Hall, Upper Saddle River, 2005)
16. M.R. Cutkosky, *Robot Grasping and Fine Manipulation* (Kluwer Academic, Boston, 1985)
17. J. Denavit, R.S. Hartenberg, *J. Appl. Mech.* **22**(2), 215 (1955)
18. R. Di Gregorio, V. Parenti-Castelli, in *Advances in Robot Kinematics: Analysis and Control*, ed. by J. Lenarčič, M.L. Husty (Kluwer Academic, Dordrecht, 1998), pp. 49–58
19. F. DiCaprio, M.M. Stanišić, *J. Mech. Des.* **116**(1), 17 (1994)
20. P. Dietmaier, in *Advances in Robot Kinematics: Analysis and Control* (Kluwer Academic, Dordrecht, 1998), pp. 7–16
21. J. Duffy, *Analysis of Mechanisms and Robot Manipulators* (Arnold, London, 1980)
22. R. Featherstone, *Int. J. Robot. Res.* **2**(2), 35 (1983)
23. R. Featherstone, *Robot Dynamics Algorithms* (Kluwer Academic, Dordrecht, 1987)
24. J. Furusho, S. Onishi, in *Proceedings 15th International Conference on Industrial Robots*, Tokyo (1985), pp. 1051–1058
25. C. Gosselin, J. Angeles, *J. Mech. Transm. Autom. Des.* **110**, 35 (1988)
26. V.E. Gough, S.G. Whitehall, in *Proceedings 9th International Technical Congress F.I.S.I.T.A.*, Institution of Mechanical Engineers (1962), pp. 117–135
27. J.M. Hollerbach, K.C. Suh, *IEEE J. Robot. Autom.* **3**(3), 308 (1987)

28. M. Honegger, A. Codourey, E. Burdet, in *Proceedings IEEE Robotics and Automation Conference*, Albuquerque (1997)
29. K.H. Hunt, *Kinematic Geometry of Mechanisms* (Clarendon Press, Oxford, 1978)
30. K.H. Hunt, *J. Mech. Transm. Autom. Des.* **105**, 705 (1983)
31. M.L. Husty, *Mech. Mach. Theory* **31**(4), 365 (1996)
32. T. Iberall, *Int. J. Robot. Res.* **16**, 285 (1997)
33. C. Innocenti, V. Parenti-Castelli, *Mech. Mach. Theory* **28**(4), 553 (1993)
34. J. Kieffer, *IEEE Trans. Robot. Autom.* **10**(1), 1 (1994)
35. J. Kieffer, J. Lenarčič, in *Proceedings 3rd International Symposium on Advances in Robot Kinematics*, Ferrara, Italy (1992), pp. 65–72
36. C.A. Klein, C.H. Huang, *IEEE Trans. Syst. Man Cybern.* **13**(3), 245 (1983)
37. C.A. Klein, C. Chu-Jenq, S. Ahmed, *IEEE Trans. Robot. Autom.* **11**(1), 50 (1995)
38. V.C. Klema, A.J. Laub, *IEEE Trans. Autom. Control* **25**(2), 164 (1980)
39. P. Kovacs, G. Hommel, in *Advances in Robot Kinematics*, Ferrara, Italy (1992), pp. 88–95
40. P. Kovacs, G. Hommel, in *Computational Kinematics*, ed. by J. Angeles, G. Hommel, P. Kovacs (Kluwer Academic, Dordrecht, 1993), pp. 27–39
41. A. Kumar, K.J. Waldron, *J. Mech. Des.* **103**, 665 (1981)
42. G. Kurillo, T. Bajd, R. Kamnik, *J. Autom. Control* **12**(1), 38 (2002)
43. G. Kurillo, M. Mihelj, M. Munih, T. Bajd, *Presence* **16**, 239 (2007)
44. J. Lenarčič, *Robotica* **1**, 205 (1983)
45. J. Lenarčič, *Robotica* **3**, 21 (1985)
46. J. Lenarčič, in *International Encyclopedia of Robotics*, ed. by R. Dorf (Wiley, New York, 1988)
47. J. Lenarčič, *Lab. Robot. Autom.* **6**(6), 293 (1994)
48. J. Lenarčič, *Lab. Robot. Autom.* **8**, 11 (1996)
49. J. Lenarčič, in *Proceedings IEEE International Conference on Robotics and Automation*, Leuven, Belgium (1998), pp. 3235–3240
50. J. Lenarčič, *Robot. Auton. Syst.* **30**, 231 (2000)
51. J. Lenarčič, *CIT, J. Comput. Inf. Technol.* **10**(2), 125 (2002)
52. J. Lenarčič, M.M. Stanišić, *IEEE Transactions on Robotics and Automation* **19** (2003)
53. J. Lenarčič, U. Stanič, U. Oblak, *Robot. Comput.-Integr. Manuf.* **5**(2/3), 235 (1989)
54. J. Lenarčič, U. Stanič, P. Oblak, in *Proceedings 23rd International Symposium on Industrial Robots*, Barcelona, Spain (1992), pp. 277–282
55. J. Lenarčič, M.M. Stanišić, V. Parenti-Castelli, in *Proceedings IEEE Robotics and Automation Conference*, San Francisco (2000), pp. 27–32
56. A.A. Maciejewski, C.A. Klein, *Int. J. Robot. Res.* **4**(3), 109 (1985)
57. M.T. Mason, J.K. Salisbury, *Robot Hands and the Mechanics of Manipulation* (MIT Press, Cambridge, 1985)
58. J.M. McCarthy, *An Introduction to Theoretical Kinematics* (MIT Press, Cambridge, 1990)
59. J.M. McCarthy, *Geometric Design of Linkages* (Springer, New York, 2000)
60. J.P. Merlet, *Parallel Robots*, 2nd edn. (Springer, Dordrecht, 2006)
61. V. Milenkovic, in *Robots II, RISM* (1987), pp. 13.29–13.42
62. Y. Nakamura, H. Hanafusa, T. Yoshikawa, *Int. J. Robot. Res.* **6**(2), 3 (1987)
63. J. Napier, *J. Bone Jt. Surg.* **38-B**, 902 (1956)
64. J. Napier, *Hands* (Princeton University Press, Princeton, 1980)
65. D.N. Nenchev, *J. Robot. Syst.* **6**(6), 769 (1989)
66. V. Parenti-Castelli, R. Di Gregorio, in *Advances in Robot Kinematics*, ed. by J. Lenarčič, M.M. Stanišić (Kluwer Academic, Dordrecht, 2000), pp. 333–334
67. R. Paul, *Robot Manipulators: Mathematics, Programming and Control* (MIT Press, Cambridge, 1981)
68. R.P. Paul, C.N. Stevenson, *Int. J. Robot. Res.* **2**(1), 31 (1983)
69. D.L. Pieper, B. Roth, in *Proceedings 2nd International Congress of the Theory of Machines and Mechanisms*, Zakopane, Poland (1969), pp. 159–169
70. S. Remis, M.M. Stanišić, *IEEE Trans. Robot. Autom.* **9**(6), 816 (1993)

71. R.G. Roberts, A.A. Maciejewski, *IEEE Trans. Robot. Autom.* **12**(4), 543 (1996)
72. M. Rosheim, *Robot Evolution, The Development of Anthropotics* (Wiley, New York, 1994)
73. B. Roth, in *Computational Kinematics*, ed. by J. Angeles, G. Hommel, P. Kovacs (Kluwer Academic, Dordrecht, 1993), pp. 3–14
74. B. Roth, in *Advances in Robot Kinematics and Computational Geometry*, ed. by J. Lenarčič, B. Ravani (Kluwer Academic, Dordrecht, 1994), pp. 7–16
75. A. Ružič, in *Proceedings 4th Workshop on Robotics in Alpe-Adria Region*, Pörschach, Austria (1995), pp. 59–62
76. S.J. Ryu, J. Kim, J.C. Hwang, C.B. Park, H.S. Cho, K. Lee, Y.H. Lee, U. Cornel, F.C. Park, J.W. Kim, *J. Manuf. Sci. Eng.* **8**, 681 (1998)
77. L. Sciavicco, B. Siciliano, *Modeling and Control of Robot Manipulators*, 2nd edn. (Springer, London, 2000)
78. M.M. Stanišić, O. Duta, *IEEE Trans. Robot. Autom.* **6**(5), 562 (1990)
79. Y. Stepanenko, M. Vukobratović, *Math. Biosci.* **28**, 137 (1976)
80. D. Stewart, *Proc. Inst. Mech. Eng.* **180**, 371 (1965)
81. T. Šupuk, T. Kodek, T. Bajd, *Engineering & Physics* **27**, 790 (2005)
82. J. Trevelyan, P. Kovesi, M. Ong, D. Elford, *Int. J. Robot. Res.* **4**(4), 71 (1986)
83. L.W. Tsai, in *Recent Advances in Robot Kinematics*, ed. by J. Lenarčič, V. Parenti-Castelli (Kluwer Academic, Dordrecht, 1996), pp. 401–409
84. L.W. Tsai, *Robot Analysis, The Mechanics of Serial and Parallel Manipulators* (Wiley, New York, 1999)
85. M. Veber, T. Kodek, T. Bajd, M. Munih, *Meccanica* **42**, 451 (2007)
86. M. Vukobratović, M. Kirčanski, *Kinematics and Trajectory Synthesis of Manipulation Robots* (Springer, Berlin, 1986)
87. C.W. Wampler, A.P. Morgan, A.J. Sommesse, *J. Mech. Des.* **112**, 59 (1990)
88. P. Wenger, D. Chablat, in *Advances in Robot Kinematics*, ed. by J. Lenarčič, M.M. Stanišić (Kluwer Academic, Dordrecht, 2000), pp. 305–314
89. P. Wenger, J. El Omri, in *Advances in Robot Kinematics and Computational Geometry*, ed. by J. Lenarčič, B. Ravani (Kluwer Academic, Dordrecht, 1994), pp. 29–38
90. D.E. Whitney, *IEEE Trans. Man-Mach. Syst.* **MMS-10**, 47 (1969)
91. K. Wohlhart, *Mech. Mach. Theory* **29**, 581 (1994)
92. T. Yoshikawa, *Int. J. Robot. Res.* **4**(2), 3 (1985)
93. V.M. Zatsiorsky, *Kinematics of Human Motion* (Human Kinetics, Champaign, 1998)

Index

A

- Acceleration, 3, 4, 7
 - angular, 46, 110
 - Coriolis, 48
 - linear, 46
 - radial, 48
 - tangential, 48
 - translational, 110
- Angular acceleration matrix, 47, 110
- Angular velocity matrix, 39, 100
- Articulated arm, 187

C

- Connectivity, 247, 297
- Contact
 - friction, 286
 - line, 274, 282
 - plane, 274, 283, 292
 - point, 273, 280, 286, 292
 - soft finger, 284, 288
- Contact matrix, 304
- Coordinate
 - external, 91
 - generalized, 121
 - internal, 91, 121
 - joint, 121
 - rotational, 76, 79
 - translational, 76, 79
- Coordinates
 - Cartesian, 2
 - cylindrical, 3
 - external
 - primary, 209
 - secondary, 209
 - Plücker, 275
 - spherical, 5
- Cylindrical arm, 195

D

- Degree of constraints, 63
- Degrees of freedom, 62, 71
- Denavit-Hartenberg notation, 76
- Direct kinematics, 123, 258, 321
 - multiple solutions, 262
- Displacement, 9
 - continuous, 12
 - finite, 9

E

- Euler orientation angles, 32
- Euler parameters, 36

F

- Finger, 297, 314
- Friction cone, 287, 294

G

- Generalized inverse
 - non-weighted, 210
 - weighted, 210
- Grasp, 291, 293
 - power, 301
 - precision, 301
- Grasp matrix, 304
- Gripper, 297
- Grübler's formula, 72, 298
 - reformulation, 246

H

- Hand, 297
- Hessian matrix, 128
- Homogeneous matrix, 51
- Homogeneous transformation, 51
- Human arm, 68, 229
- Human hand, 313
- Human leg, 271

Humanoid shoulder, 271
Hyperredundancy, 233

I

Industrial manipulator, 69
Industrial robot, 67
Invariant
 scalar, 18, 37
 vector, 18, 37
Inverse kinematics, 130, 252, 317
 algebraic solution, 137
 gradient method, 143
 multiple solutions, 136, 169
 Newton-Raphson, 143, 212
 numerical solution, 141

J

Jacobian matrix, 123, 171
 primary, 209
 rectangular, 210
 secondary, 209
Joint, 62
 cylindrical, 63
 rotational, 63
 screw, 64
 spherical, 65
 translational, 63
 universal, 63, 315
Joint center, 85
Joint variables, 75
Joint vector, 79, 86

K

Kinematic chain
 closed, 66, 240
 open, 66
Kinematic equations, 92, 250
Kinematic flexibility, 169
Kinematic index, 178
 isotropic configuration, 184
Kinematic pair, 74
Kinematic singularity, 171, 263

L

Lagrange function, 211
Link vector, 79, 86

M

Manipulability, 178
 ellipsoid, 180
Mechanism, 62
 hyperredundant, 233
 non-redundant, 231
 orientational part, 69

 parallel, 66
 positional part, 69
 redundant, 207
 reference position, 85
 selection, 164
 serial, 66, 91
Mobility, 297, 299

N

Null space, 218
 basic vectors, 218
 projection matrix, 218

O

Orientation, 9, 29, 92
Orientation angles, 31
Orthogonal complement, 216
Orthogonal matrix, 20

P

Palm, 299
Parallel mechanism, 239
 base, 241
 Delta robot, 241, 243
 Hessian matrix, 255
 Jacobian matrix, 255
 joint coordinates, 251
 legs, 241
 parameters, 251
 platform, 241
 Stewart-Gough platform, 241, 243
Pose, 8
Position, 1, 8, 29, 92
Primary task, 208
 equal priority, 214
 higher priority, 215
 independent solution, 210
Product \otimes , 17
Pushing, 293

R

Rodrigues formula, 21
Rodrigues parameters, 37
Rotation, 9, 18, 26
Rotation angle, 29
Rotation matrix, 18, 22, 92
Rotation vector, 29

S

Scalar parameters, 76
Scara arm, 199
Screw, 275
Secondary task, 208
 independent solution, 210
 subordinated, 217

Self motion, 208
 curve, 224
Singular plane, 201
Singularity metric, 201
Spherical arm, 192
Spherical wrist, 137, 200
Squeezing, 293
Symmetric actuation, 202

T

Task priority method, 216
Thumb, 297, 319
Translation, 9, 26
Translation vector, 25
Twist, 275, 279, 291

V

Vector parameters, 78, 314
Velocity, 3, 4, 6

angular, 38, 100
ellipsoid, 182
linear, 38
translational, 100

W

Wedging, 294
Weighting matrix, 210
 optimal, 219
Workspace, 151
 compactness, 166
 determination, 156, 158
 dexterous, 162
 reachable, 152
 volume, 164
Wrench, 275, 277, 291

Y

YPR orientation angles, 34