

Accelerations, link, 102  
 Active impedance, 211, 214, 218  
 Actuator dynamics, 197  
 Actuators, 167  
 Adaptive control, 199  
 Algebraic approach, 45  
 Angular momentum, 82  
     velocity vector, 54  
 Arm mechanisms, 2  
 Artificial constraints, 226  
 Assignment of poles, 193  
 Asymptotically stable, 168, 272  
 $\text{atan}2$ , 20, 259  
 Avoiding obstacles, 249  
 Avoiding singularities, 253  
 Centrifugal force, 90  
 Complementary sensitivity function, 189  
 Compliance center, 214  
 Compliance control, 222  
 Computation, amount of, 175  
 Computational load, 108  
 Computed torque method, 174  
 Condition number, 143  
 Constraining force, 231  
 Constraint frame, 224, 229  
 Constraint surfaces, 228  
 Control, 9  
     dynamic hybrid, 227  
     force, 211  
     hybrid, 222  
     of redundant manipulators, 244  
     position, 155  
 Controller, 9  
 Control subsystem, 1  
 Coordinate transformation, 23  
 Coriolis force, 91  
 Cosine theorem, 260  
 Coupling inertia, 90  
 Criterion function, 248  
 Cylindrical-coordinate manipulators, 2, 139  
 Damping coefficient, 184  
 Decoupling control, 192  
 Degrees of freedom, 2  
 Denavit-Hartenberg notation, 33  
 Desired trajectory, 155, 247  
 Direct dynamics problem, 109  
 Direct kinematics problem, 29, 39  
 Direction cosine matrix, 17  
 Disturbances, 172  
 DME, 145  
 Double-axis rotation method, 164  
 Dual-sampling-rate approach, 176

Dynamic hybrid control, 227  
 Dynamic manipulability, 143  
 Dynamic-manipulability ellipsoid,  
 Dynamic-manipulability measure,  
 Dynamic parameters, 112  
 Dynamics, 81  
 Effective inertia, 90  
 Elbow singularities, 70  
 Elephant Trunk wrist, 4  
 End effector, 39, 161, 227  
     position of, 28  
     velocity of, 57  
 Equations of motion, 81  
 Equivalent angle of rotation, 163  
 Equivalent axis of rotation, 163  
 ET wrists, 4  
 Euclidean norm, 128, 247  
 Euler angles, 18  
 Euler method, 111  
 Euler's equation, 82  
 Evaluation of manipulators, 127  
 Feedback compensator, 188  
 Feedforward compensator, 188  
 Fingers, 139  
 Force, 71, 231  
 Force control, 9, 211  
 Force sensor, 11, 73, 120  
 Force servo loop, 237  
 Four-degrees-of-freedom wrist, 4  
 Frame, 13  
 Friction, 106, 121  
 Gear ratio, 183  
 Generalized coordinates, 86  
 Generalized force, 87  
 Geometric approach, 45  
 Globally asymptotically stable, 273  
 Gravity force, 91  
 Hand, 14, 73, 139  
     RCC, 212  
 Homogeneous transform, 23  
 Horizontal multi-joint type, 2  
 Hybrid control, 222  
     dynamic, 227  
 IBM 7565 robotic system, 8  
 Identifiable parameter, 115  
 Identificartion, 112  
     of load, 122  
 Impedance control, 211  
 Indices of manipulability, 142

Inertia matrix, 91  
 Inertia tensor, 83, 93  
 Inertial coordinate frame, 82  
 Inertial force, 90  
 Instantaneous axis of rotation, 54  
 Instantaneous optimization problem, 249  
 Integral action, 170  
 Intermediate point, 158  
 Inverse dynamics, 177  
 Inverse dynamics problem, 108  
 Inverse kinematics problem, 29, 45  
 Inverse, of homogeneous transform, 26  
     pseudo-, 67, 256, 263  
 Jacobian matrix, 53, 57, 63, 246  
 Joint actuators, 9  
 Joint angle, 33  
 Joint axis, 33  
 Joint length, 33  
 Joint variable, 28  
 Joint-variable scheme, 155  
 Joint vector, 28  
 Joint velocity, 57  
 Kawasaki Unimate, 8  
 Kinematic equation, 29, 47, 51  
 Kinematic parameters, 112  
 Kinematics, 13  
 Kinetic energy, 87  
 Lagrange's equation, 86  
 Lagrangian formulation, 81, 113  
 Lagrangian function, 87  
 Linear feedback control, 166  
 Linearization, 170  
 Linearizing compensation, 193  
 Link accelerations, 102  
 Link frames, 33  
 Link length, 33  
 Link parameters, 31  
 Lyapunov function, 169, 203, 273  
 Lyapunov stability theorem, 168  
 Lyapunov stability theory, 202, 272  
 Manipulability, 127  
     dynamic, 143  
 Manipulability ellipsoid, 128  
 Manipulability measure, 131, 255  
 Manipulating-force ellipsoid, 133  
 Manipulation vector, 246  
 Manipulators, 1  
 Mechanisms, 1  
 Modeling error, 172  
 Moment, 72

Moments of inertia, 84  
 Momentum, 82  
 Motion subsystem, 1  
 Natural angular frequency, 184  
 Natural constraints, 226  
 Negative definite, 275  
 Newton's equation, 82  
 Newton-Euler formulation, 81, 100  
 Normalization, 131, 146  
 Nyquist stability criterion, 189  
 Object frame, 13  
 Obstacle, 249  
 Open-loop link mechanisms, 1  
 Optimal configurations, 133  
 Orientation of objects, 13  
 Orthogonal-coordinate manipulators, 2, 139  
 Parallel-axis theorem, 94  
 Parallel drive, 98, 125  
 Parallel processing, 176  
 Parallelogram, 125  
 Parameter estimation, 202  
 Passive impedance, 211  
 Perspective transform, 78  
 PI control law, 224  
 PID control law, 224  
 Pieper's approach, 51  
 Pivot join, 1  
 Point-to-point control, 168  
 Polar-coordinate manipulators, 2, 139  
 Polynomial, 156  
 Position control, 9, 155  
     of objects, 13  
     servo loop, 237  
 Positioning accuracy, 2  
 Positive definite, 275  
 Potential energy, 87  
 Principal axes,  
     of manipulability ellipsoid, 130  
     of moment of inertia, 86  
 Principal minors, 276  
 Prismatic joint, 1, 63, 65  
 Processor, 177  
 Product of homogeneous transform, 26  
 Products of inertia, 84  
 Pseudo inertia matrix, 92  
 Pseudo-inverse, 67, 256, 263  
 PUMA, 6, 40, 52, 65, 70, 137  
 RCC hand, 212  
 Reachable region, 70

Real time, 109  
Recognition subsystem, 1  
Reduction ratios, 167  
Redundant manipulators, 244  
Redundant representation, 17  
Reference frame, 13  
Regularization, 256  
Remote center compliance hand, 212  
Representational singularities, 56  
Resolved acceleration control, 174  
Revolute joint, 1, 63, 64  
Robot system, 1  
Robustness, 187  
Roll, pitch, and yaw angles, 22  
Rotation,  
  equivalent angle of, 163  
  equivalent axis of, 163  
Rotation matrix, 14  
Runge-Kutta method, 111  
  
Sampling period, 175  
SCARA, 9, 135  
Second-order system, 185  
Sensitivity, 187, 239  
  function, 189  
Sensors, 9, 11  
Serial drive, 91  
Servo compensation, 170  
Servo compensators, 182  
Servomechanism, 9  
Servomotor, 182  
Shoulder singularities, 70  
Simulation, 110  
Single-axis rotation method, 163  
Singular configuration, 4, 67, 131, 196, 253  
Singular-value decomposition, 129, 264, 268  
Singular values, 268  
Singularities, 70  
  representational, 56  
Skew coordinate system, 56  
Small gain theorem, 189  
Stability, 272  
Stability margin, 187, 239  
Stanford manipulator, 36  
Statics, 71  
Step response, 184  
Stiffness control, 222  
Stretching transform, 78  
Subtasks, 177, 245  
Sylvester's criterion, 276  
  
T3-786 robot, 7  
Task-decomposition approach, 245  
Third-order decoupled system, 198