

Contents

Part I: Control of Nonholonomic Systems

1 Geometrical Properties of Aircraft Equilibrium and Nonequilibrium Trajectory Arcs	3
<i>Yasmina Bestaoui</i>	
1.1 Introduction	3
1.2 Modeling	4
1.3 Parametric Curves	5
1.3.1 Trim Flight Paths	6
1.3.2 Nontrim Flight Paths	8
1.3.3 Maneuvers	10
1.4 Conclusions	11
References	11
2 Identification of a UAV Model for Control	13
<i>Piotr Cieciński, Jacek Pieniążek</i>	
2.1 Introduction	13
2.2 Measurement System	14
2.2.1 UAV Model of Motion	14
2.2.2 Structure of the Measurement System	15
2.3 Model of a UAV Motion in Control Algorithms Design	16
2.4 Identification Method	18
2.4.1 General Idea of the Identification	18
2.4.2 Experiment Layout	19
2.5 Effects of Characteristics of Measurements on Model Quality	19
2.5.1 Dynamics, Noise, and Inaccuracies	20
2.5.2 Examples of Effects	20
2.6 Conclusions	22
References	22

3 Finite-time VFO Stabilizers for the Unicycle with Constrained Control Input	23
<i>Maciej Michałek, Krzysztof R. Kozłowski</i>	
3.1 Introduction	23
3.2 Prerequisites	24
3.3 Principles of the VFO Control Strategy	25
3.4 Finite-time VFO Stabilizers	27
3.5 Numerical Tests	31
3.6 Conclusions	32
Appendix	33
References	34
4 Nonsmooth Stabilizer for Three Link Nonholonomic Manipulator Using Polar-like Coordinate Representation	35
<i>Dariusz Pazderski, Krzysztof R. Kozłowski, Bartłomiej Krysiak</i>	
4.1 Introduction	35
4.2 Three Link Nonholonomic Manipulator	36
4.2.1 Kinematic Structure	36
4.2.2 Controllability Analysis	37
4.3 Control Development	38
4.3.1 Control Task Formulation and Open-loop Kinematic Error	38
4.3.2 Control Design	39
4.4 Simulation Results	42
4.5 Concluding Remarks	43
Appendix	43
References	44
5 Kinematic Tracking Controller for Unicycle Mobile Robot Based on Polar-like Representation and Lyapunov Analysis	45
<i>Dariusz Pazderski, Paweł Szulczyński, Krzysztof R. Kozłowski</i>	
5.1 Introduction	45
5.2 Model Description	46
5.2.1 Plane Motion and Tracking Error Description	46
5.2.2 Constrained Planar Motion – Unicycle Case	47
5.3 Control Development	47
5.3.1 Preliminary Stability Analysis – Position Control	48
5.3.2 Orientation Control	50
5.4 Simulation Results	53
5.5 Concluding Remarks	55
Appendix	55
References	56

6 Trajectory Tracking for Formation of Mobile Robots	57
<i>Wojciech Kowalczyk, Krzysztof R. Kozłowski, József K. Tar</i>	
6.1 Introduction	57
6.2 Control Algorithm	58
6.2.1 Model of the System	58
6.2.2 Collision Avoidance	58
6.2.3 Control	59
6.3 Stability Analysis	60
6.3.1 Collision Avoidance with Single Obstacle	60
6.3.2 Collision Avoidance Between N Robots	62
6.3.3 Proof of Convergence of Robots Orientation to Auxiliary Orientation Variable	63
6.3.4 Proof of Convergence of Auxiliary Orientation Variable to Reference Orientation	63
6.4 Simulation and Experimental Results	64
6.4.1 Simulations	64
6.4.2 Experiments	64
6.5 Conclusion	65
References	66

Part II: New Control Algorithms for Robot Manipulators

7 Feedback Stabilization of a System of Rigid Bodies with a Flexible Beam	69
<i>Alexander Zuyev</i>	
7.1 Introduction	69
7.2 Equations of Motion	70
7.3 Main Results	73
7.4 Simulation Results	79
7.5 Conclusion	81
References	81
8 Application of the Return Method to the Steering of Nonlinear Systems	83
<i>Tetiana Chumachenko, Alexander Zuyev</i>	
8.1 Introduction	83
8.2 Main Results and Examples	84
8.3 Application to the Steering Problem	89
8.4 Concluding Remarks	91
References	91

9 Application of Robust Fixed Point Transformations for Technological Operation of Robots	93
<i>József K. Tar, Imre J. Rudas, Krzysztof R. Kozłowski, José A. Tenreiro Machado</i>	
9.1 Introduction	93
9.2 Technological Operations and Fixed Point Transformations	95
9.3 The Model of the Application Paradigm and Simulation Results	98
9.4 Conclusions	100
References	101
10 Fixed Point Transformations in the Adaptive Control of Fractional-order MIMO Systems	103
<i>József K. Tar, Imre J. Rudas, László Nádai, Krzysztof R. Kozłowski, José A. Tenreiro Machado</i>	
10.1 Introduction	103
10.2 The Discrete Time Approximation of Caputo's Fractional Derivatives	104
10.3 The 2D FO Generalization of the Φ^6 -type Van Der Pol Oscillator	107
10.4 Operation of the Adaptive Control	107
10.5 Conclusions	110
References	111
11 Fractional-order Mathematical Model of Pneumatic Muscle Drive for Robotic Applications	113
<i>Edward Jezierski, Piotr Ostalczyk</i>	
11.1 Introduction	113
11.2 Pneumatic Muscle Description	114
11.3 Mathematical Preliminaries	115
11.4 Dynamic Model of a Pneumatic Muscle	119
11.5 Concluding Remarks	122
References	122
12 Combinatorial Control Systems	123
<i>Jesper Abildgaard Larsen, Rafael Wisniewski</i>	
12.1 Introduction	123
12.2 Methodology	124
12.2.1 Simplicial Complex	124
12.2.2 Control Combinatorial Vector Fields	126
12.2.3 Combinatorial Vector Fields	127
12.2.4 Lyapunov Function	128
12.2.5 Control Synthesis	129
12.3 Example	130

12.4 Conclusion	132
References	132
13 Computational Algebra Support for the Chen–Fliess–Sussmann Differential Equation	133
<i>Ignacy Duleba, Jacek Jagodziński</i>	
13.1 Introduction	133
13.2 Preliminaries	135
13.3 An Algorithm to Derive the CFS Equation	137
13.4 Simulations	139
13.5 Conclusions	142
References	142
Part III: Control of Walking Robots	
14 Biologically Inspired Motor Control for Underactuated Robots – Trends and Challenges	145
<i>Fumiya Iida</i>	
14.1 Introduction	145
14.2 Mechanical Feedback for Self-stability	146
14.3 Body Dynamics for Behavioral Diversity	149
14.4 Controlling Nonlinear Dynamics	150
14.5 Conclusion	153
References	153
15 Adaptation of a Six-legged Walking Robot to Its Local Environment	155
<i>Arne Roennau, Thilo Kerscher, Marco Ziegenmeyer, Johann Marius Zöllner, Rüdiger Dillmann</i>	
15.1 Introduction	155
15.2 LAURON: A Six-legged Walking Robot	156
15.3 Behavior-Based Control of LAURON	157
15.4 Environment Modeling with a Time-of-flight Camera	158
15.5 Localisation of a Robot with a Time-of-Flight Camera	159
15.6 Adaptation of the Robot to the Environment	161
15.7 Conclusion and Outlook	163
References	163
16 Development of Two-legged Robot	165
<i>Teresa Zielińska, Andrzej Chmielnik</i>	
16.1 Introduction	165
16.2 Human and Robot Structure	165
16.3 Design Study	166
16.4 Robot Gait	169
16.5 Conclusions	172
References	173

17 Quadruped Walking Robot WR-06 – Design, Control and Sensor Subsystems	175
<i>Mateusz Michalski, Michał Kowalski, Dariusz Pazderski</i>	
17.1 Introduction	175
17.2 Mechanical Structure	176
17.3 Analysis of Mechanical Properties	176
17.4 Control System Architecture	178
17.5 On-board Sensors	179
17.6 Robot Body Orientation Measurement	180
17.7 Concluding Remarks	184
References	184
18 Population-Based Methods for Identification and Optimization of a Walking Robot Model	185
<i>Dominik Belter, Piotr Skrzypczyński</i>	
18.1 Introduction	185
18.2 The Robot and the Simulator	186
18.3 Methods for Model Optimization	187
18.3.1 Evolutionary Algorithm	187
18.3.2 Particle Swarm Optimization	188
18.4 Robot Model Optimization	189
18.5 Results	191
18.6 Conclusions and Future Work	193
References	195
19 Static Equilibrium Condition for a Multi-leg, Stairs Climbing Walking Robot	197
<i>Krzysztof Walas</i>	
19.1 Introduction	197
19.2 Static Equilibrium	198
19.3 Center of Mass Variation of a Walking Robot	200
19.4 Stability Analysis System for a Walking Robot	202
19.5 Case Study of the Stability Check for the Robot “Ragno”	203
19.6 Special Cases for Stability Check in Stair Climbing	204
19.7 Conclusions and Future Work	205
References	206
Part IV: Compliant Motion and Manipulation	
20 Human-Aware Interaction Control of Robot Manipulators Based on Force and Vision	209
<i>Luigi Villani, Agostino De Santis, Vincenzo Lippiello, Bruno Siciliano</i>	
20.1 Introduction	209
20.2 Modeling	210

20.2.1 Human User	210
20.2.2 Environment	212
20.2.3 Robot	212
20.2.4 Camera	213
20.3 Use of Vision, Force, and Joint Positions Measurements	214
20.3.1 Vision	214
20.3.2 Force	215
20.3.3 Joint Positions	216
20.4 Vision-Based Pose Estimation	216
20.4.1 Human Operator's Pose Estimation	216
20.4.2 Object Pose Estimation	217
20.5 Interaction Control	218
20.5.1 Hybrid Force/Position Control	218
20.5.2 Impedance Control	219
20.6 Case Studies	220
20.6.1 Interaction with an Object	221
20.6.2 Vision-Based Head Avoidance	223
20.7 Conclusion	224
References	224
21 Specification of Multi-robot Controllers on an Example of a Haptic Device	227
<i>Tomasz Winiarski, Cezary Zieliński</i>	
21.1 Introduction	227
21.2 An Embodied Agent	227
21.3 General Structure of Images	229
21.4 Transition Functions and the Motion Instruction	230
21.5 Elementary Behaviors	232
21.6 The Effector Driver	233
21.7 Haptic Interface	234
21.7.1 Images Employed by the Agents	234
21.7.2 Transition Functions and Terminal Conditions	235
21.8 Experimental Results	237
21.9 Conclusions	241
References	242
22 Characterization of the Dynamical Model of a Force Sensor for Robot Manipulators	243
<i>Ezio Bassi, Francesco Benzi, Luca Massimiliano Capisani, Davide Cuppone, Antonella Ferrara</i>	
22.1 Introduction	243
22.2 Sensor Measurements	244
22.3 The Kinematic Model of the Robot	245
22.4 Sensor and Tip Dynamical Model	246
22.5 Estimation of the Contact Force	248

22.6 Description of the Considered Robotic System	249
22.7 Experimental Results	250
22.8 Conclusions	252
References	252
23 Inverse Kinematics for Object Manipulation with Redundant Multi-fingered Robotic Hands	255
<i>Vincenzo Lippiello, Fabio Ruggiero, Luigi Villani</i>	
23.1 Introduction	255
23.2 Kinematics of Object and Fingers	256
23.3 Contact Kinematics	256
23.4 Kinematic Classification of Grasp	259
23.5 Inverse Kinematics with Redundancy Resolution	260
23.6 Case Study	261
23.7 Conclusion	264
References	264
24 Compliant Motion Control for Safe Human Robot Interaction	265
<i>Rehan M. Ahmed, Anani V. Ananiev, Ivan G. Kalaykov</i>	
24.1 Introduction	265
24.2 Experimental Safe Robot Prototype	266
24.3 Interaction Scenarios and Control Disciplines	268
24.4 Experimental Setup and Results	270
24.5 Conclusion	273
References	273
Part V: Trajectory Planning Issues for Nonholonomic Systems	
25 Nonholonomic Motion Planning of Mobile Robots	277
<i>Miroslaw Galicki</i>	
25.1 Introduction	277
25.2 Nonholonomic Mobile Robot Kinematics	279
25.3 Robot Motion Planning	280
25.3.1 Path Planning	280
25.3.2 Collision Avoidance Path	282
25.4 Controls of the Mobile Robot	283
25.5 Numerical Example	284
25.6 Conclusions	285
References	285
26 Minimum-Time Velocity Planning with Arbitrary Boundary Conditions	287
<i>Gabriele Lini, Aurelio Piazzi</i>	
26.1 Introduction	287

26.2 Problem Statement and the Structure of the Optimal Solution	288
26.3 The Algebraic Solution	290
26.4 The Minimum-time Algorithm	292
26.5 Examples	294
26.6 Conclusion	295
References	296
27 Motion Planning for Highly Constrained Spaces	297
<i>Anna Yershova, Steven M. LaValle</i>	
27.1 Introduction	297
27.2 The Motion Planning Problem	299
27.3 Dynamic Domain RRT Planner	300
27.4 Representing Feasible Configuration Spaces with Kd-trees	302
27.5 Experimental Results	304
27.6 Conclusions and Future Work	305
References	306
28 RRT-path – A Guided Rapidly Exploring Random Tree	307
<i>Vojtěch Vonásek, Jan Faigl, Tomáš Krajiník, Libor Přeučil</i>	
28.1 Introduction	307
28.2 Related Work	308
28.3 RRT-path	309
28.3.1 Generating Auxiliary Path	309
28.3.2 Parametrization of Auxiliary Path	312
28.3.3 Sampling Configurations along Auxiliary Path	312
28.4 Experiments	313
28.5 Conclusion	315
References	316

Part VI: New Trends in Localization Methods

29 Position Estimation Techniques for Mobile Robots	319
<i>Levente Tamas, Gheorghe Lazea, Andras Majdik, Mircea Popa, Istvan Szoke</i>	
29.1 Introduction	319
29.2 State Estimation Techniques	320
29.2.1 Extended Kalman Filter	320
29.2.2 Unscented Kalman Filter	321
29.2.3 The Unscented Particle Filter	323
29.3 Modeling and Simulation	324
29.3.1 The Process Model	324
29.3.2 Process Error Model	325

29.3.3 Observation Model	325
29.3.4 Filter Performance Analyzes	325
29.4 Experimental Results	327
29.4.1 Odometric Measurements	327
29.4.2 Ultrasonic Measurements	327
29.4.3 Using the Ultrasonic Measurements for Position Correction	327
29.5 Conclusions	328
References	328
30 Particle Filtering with Range Data Association for Mobile Robot Localization in Environments with Repetitive Geometry	329
<i>Yi Lu, Vladimir Polotski, Jurek Z. Sasiadek</i>	
30.1 Introduction	329
30.2 Particle Filter Based on LRS Data Association and Matching	331
30.2.1 Particle Filter Algorithm Description	331
30.2.2 Particle Filter Validation by Simulations	333
30.3 Discussion	336
30.4 Conclusions and Future Works	338
References	338
31 Observable Formulation SLAM Implementation	339
<i>Abdelkarim Souici, Abdelaziz Ouldali, Raja Chatila</i>	
31.1 Introduction	339
31.2 EKF-Based World-centric SLAM	340
31.3 Description of the Observable Formulation EKF-SLAM Execution Procedure	345
31.4 Results	346
31.5 Conclusion	347
References	347
32 Estimation of Velocity Components Using Optical Flow and Inner Product	349
<i>Leonardo Fermín-León, Wilfredis Medina-Meléndez, Claudia Pérez-D'Arpino, Juan C. Grieco</i>	
32.1 Introduction	349
32.2 Motion Structure	350
32.3 Basis Expansion	351
32.4 Experiments	355
32.5 Conclusion	358
References	358

Part VII: Sensors and New Challenges in Design of Modular Robots

33 Acoustic Coupling on the Robot Motion and Control	361
<i>Kassiani Kotsidou</i>	
33.1 Introduction	361
33.2 Rudimentary Problem	362
33.3 Physical and Electro-mechano-acoustical Model	366
33.4 Output Pressure	366
33.5 Application to Robotics	368
33.6 Conclusion	369
References	370
34 Design of a Planar High Precision Motion Stage	371
<i>Gyula Hermann, József K. Tar, Krzysztof R. Koźłowski</i>	
34.1 Introduction	371
34.2 Stage Construction	373
34.3 The Measurement System	373
34.4 The Geometric Model of the Measurement System	374
34.5 The Error Model	375
34.6 The Piezo Drive	377
34.7 Motion Control	377
34.8 The Software Implementation	378
34.9 Experimental Results	378
34.10 Conclusions	378
References	379
35 Hexa Platform as Active Environment System	381
<i>Rafał Osypiuk</i>	
35.1 Introduction	381
35.2 Hexa Platform	382
35.2.1 Mechanics	383
35.2.2 Drives	383
35.2.3 Control	384
35.3 Model of Impact with Dynamic Environment	385
35.4 Experimental Setup	387
35.5 Conclusions	389
References	389
36 A Modular Concept for a Biologically Inspired Robot	391
<i>Jörg Mäppel, R. Eisold, Wolfgang Kempf, Cornelius Schilling, Hartmut Witte</i>	
36.1 Motivation	391
36.2 Climbing Robots – A Survey	392
36.2.1 Classification by Substrate Contact	393
36.2.2 Classification by Characteristics of Locomotion	394

36.2.3 Properties of Modular Robots	394
36.3 Design of the Climbing Robot “Raupi”	395
36.3.1 Locomotion Module	395
36.3.2 Gripper Module	395
36.3.3 Hardware Structure for Control	396
36.3.4 Power Source	397
36.4 Examples of Robot Configuration	397
36.5 Conclusion	398
References	399
37 Control System for Designed Mobile Robot – Project, Implementation, and Tests	401
<i>Stanisław Kozłowski, Jarosław Majchrzak</i>	
37.1 Introduction	401
37.2 Robot Construction	402
37.3 Control System Requirements	404
37.4 Control System Design and Implementation	404
37.4.1 Robot Communication System	404
37.4.2 On-board Controller Software	404
37.5 Control Algorithm	406
37.5.1 Time-Varying Feedback and Stabilization Control	407
37.5.2 Test Results	408
37.6 Summary	409
References	410
38 Team of Specialized Mobile Robots for Group Inspection of Large-Area Technical Objects	411
<i>Wojciech Moczulski, Marek Adamczyk, Marcin Januszka, Wawrzyniec Panfil, Piotr Przystałka, Marek Wyleżoł</i>	
38.1 Introduction and Motivation	411
38.2 Basic Unit – Transport Robot	412
38.3 Inspecting Robots	415
38.4 Integration Issues of Group of Robots	416
38.5 Environmental Tests of Robots	418
38.6 Conclusion and Further Work	419
References	419
Part VIII: Applications of Robotic Systems	
39 Muscle Test and Exercise System for Upper Limbs Using 3D Force Display Robot	423
<i>Yoshifumi Morita, Yuichi Furuhashi, Masaya Nagasaki, Toshimasa Aoki, Hiroyuki Ukai, Nobuyuki Matsui</i>	
39.1 Introduction	423

39.2 Rehabilitation Training Support System for Personalized Rehabilitation	424
39.3 Teaching/Guided Function for Training and Testing	426
39.4 Muscle Test Using 3D Robot	428
39.5 Muscle Exercise Using 3D Robot	429
39.6 Verification of Effectiveness by Experiments	430
39.7 Conclusions	431
References	432
40 Tests on Cardiosurgical Robot RobIn Heart 3	433
<i>Leszek Podściskowski, Paweł Żak</i>	
40.1 Introduction	433
40.2 The Construction of RobIn Heart 3	435
40.3 The Tests of RobIn Heart 3	437
40.3.1 The Research Concerning the Mechanical Parameters of the Robot Arm	437
40.3.2 Properties of Position Control Loop of the Arm of RobIn Heart 3	439
40.3.3 Properties of RobIn Heart 3 Master-slave Control Loop ..	440
40.4 Conclusions	441
References	442
41 Ankle Robot for People with Drop Foot – Case Study	443
<i>Piotr Sauer, Krzysztof R. Kozłowski, Yoshifumi Morita, Hiroyuki Ukai</i>	
41.1 Introduction	443
41.2 Mechanical Design of an Ankle Robot	445
41.3 ARM Controller	445
41.4 Experimental Results	448
41.5 Conclusions	450
References	452
42 Evolution of a Useful Autonomous System	453
<i>Artur Dubrawski, Henry Thorne</i>	
42.1 Introduction	453
42.2 From a Personal Robot to a Hospital Delivery Robot	454
42.3 The Tug Platform	455
42.4 The Tug System	459
42.5 Conclusion	461
References	462

43 Obstacle Handling of the Holonomic-driven Interactive Behavior-operated Shopping Trolley InBOT	463
<i>Michael Göller, Thilo Kerscher, Johann Marius Zöllner, Rüdiger Dillmann</i>	
43.1 Introduction	463
43.1.1 Behavior-based Control	463
43.1.2 Related Work and Discrimination.....	464
43.2 Local World Model	465
43.3 Obstacle Handling	466
43.3.1 Predictive Avoidance of Obstacles	466
43.3.2 Reactive Avoidance of Obstacles	466
43.4 Experimental Results	470
43.5 Conclusion and Outlook	471
References	472
Index	473