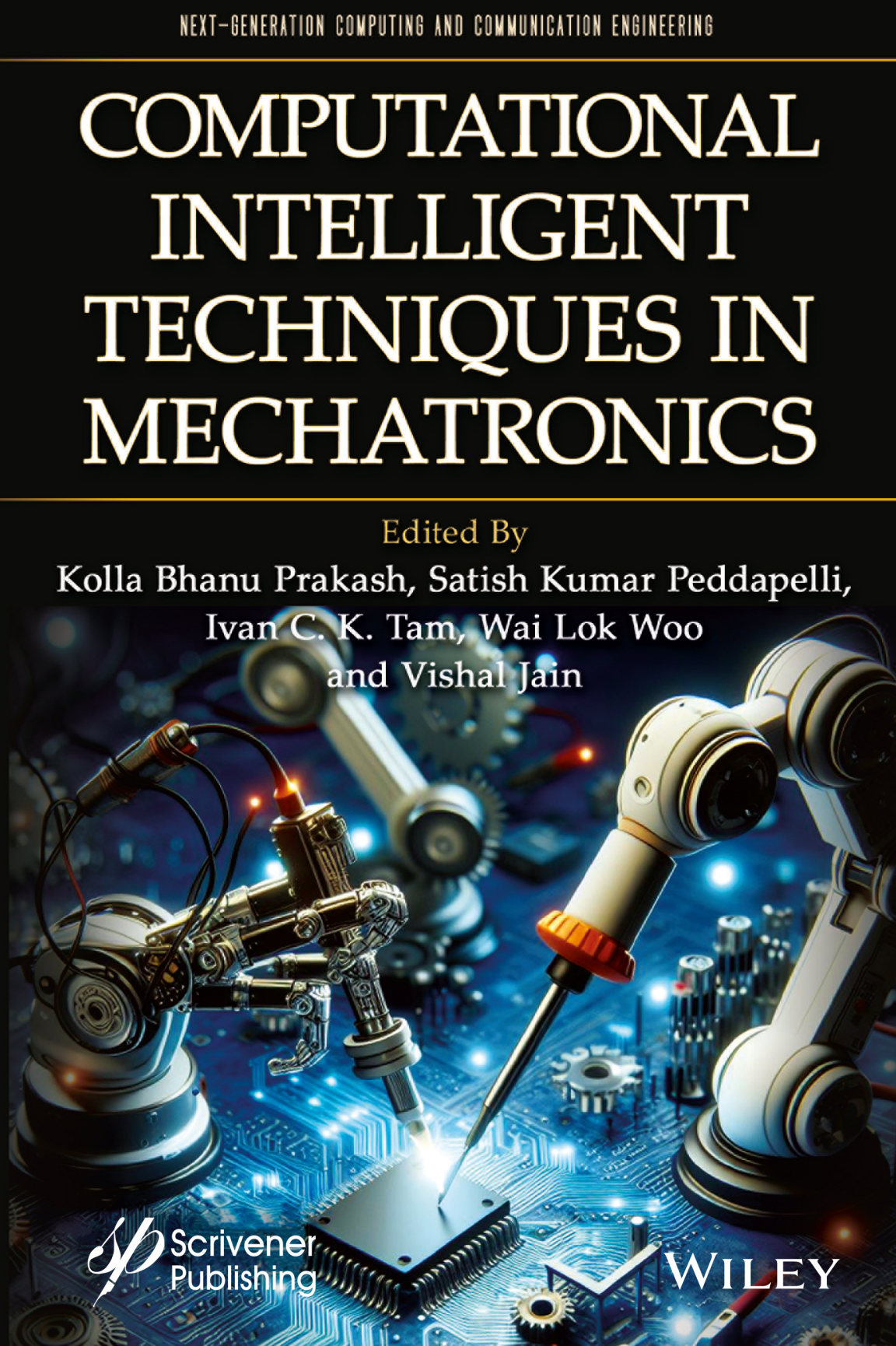


COMPUTATIONAL INTELLIGENT TECHNIQUES IN MECHATRONICS

Edited By

Kolla Bhanu Prakash, Satish Kumar Peddapelli,
Ivan C. K. Tam, Wai Lok Woo
and Vishal Jain



 Scrivener
Publishing

WILEY

Computational Intelligent Techniques in Mechatronics

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Next-Generation Computing and Communication Engineering

Series Editor: Dr. G. R. Kanagachidambaresan (kanagachidambaresan@gmail.com)
and Dr. Kolla Bhanu Prakash (drkbp1981@gmail.com)

The series concentrates on next-generation computing and communication methodologies involving smart and ambient environment design. It is an effective publishing platform for monographs, handbooks, and edited volumes on Industry 4.0, agriculture, smart city development, new computing and communication paradigms. Although the series mainly focuses on design, it also addresses analytics and investigation of industry-related real-time problems.

Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Computational Intelligent Techniques in Mechatronics

Edited by

Kolla Bhanu Prakash

*Department of Computer Science & Engineering, K. L. University,
Vaddeswaram, India*

Satish Kumar Peddapelli

Osmania University, Hyderabad, India

Ivan C. K. Tam

Director of Innovation & Engagement at the University of Newcastle in Singapore

Wai Lok Woo

*Department: Computer and Information Sciences, Northumbria University,
Newcastle, UK*

and

Vishal Jain

*Department of Computer Science and Engineering, Sharda University, Greater
Noida, India*



WILEY

This edition first published 2024 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

© 2024 Scrivener Publishing LLC

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

Wiley Global Headquarters

111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Limit of Liability/Disclaimer of Warranty

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-394-17464-5

Cover image: Pixabay.Com

Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

Preface	xxi
1 AI in Mechatronics	1
<i>Vansh Gehlot and Prashant Singh Rana</i>	
1.1 Introduction to AI Techniques for Mechatronics	2
1.1.1 Overview of Key AI Approaches	2
1.1.2 Benefits of Integrating AI in Mechatronic Systems	4
1.2 Machine Learning for Mechatronic Systems	5
1.2.1 Supervised, Unsupervised, and Reinforcement Learning Techniques	7
1.2.2 Applications in Control, Prediction, Optimization, and Diagnostics	8
1.2.3 Case Studies of Machine Learning in Robotics, Vehicles, and Automation	8
1.3 Computer Vision for Mechatronic Perception	9
1.3.1 Image Processing and Computer Vision Techniques	11
1.3.2 Enabling Environmental Perception and Scene Understanding	11
1.3.3 Vision-Based Control, Inspection, and Monitoring	12
1.4 Soft Computing Techniques	13
1.4.1 Fuzzy Logic Systems for Knowledge Representation and Control	13
1.4.2 Bio-Inspired Algorithms Like Neural Networks and Genetic Algorithms	14
1.4.3 Hybrid Intelligent Systems	15
1.5 AI Planning and Decision-Making	16
1.5.1 Automated Planning Algorithms for Sequencing Actions	16
1.5.2 Decision-Making Under Uncertainty	17

1.5.3	Applications in Navigation, Manufacturing Automation, Etc.	18
1.6	Natural Language Interaction	19
1.6.1	Speech Recognition and Natural Language Processing	19
1.6.2	Enabling Intuitive Human–Machine Interaction	20
1.6.3	Use Cases in Service Robots, Intelligent Agents, Human–Robot Collaboration	20
1.7	AI in Mechatronic System Design	21
1.7.1	Simulation of AI-Based Controllers and Behaviors	25
1.7.2	Tools for Virtual Prototyping of Intelligent Mechatronics	25
1.7.3	AI-Driven Design Optimization	26
1.8	Challenges and Future Outlook	26
1.8.1	Current Limitations in Applying AI to Mechatronics	27
1.8.2	Safety, Security, and Robustness Considerations	28
1.8.3	Emerging Trends and Opportunities	28
1.9	Artificial General Intelligence (AGI)	30
1.9.1	AGI and Narrow AI	30
1.9.2	Historical Development of AGI	31
1.9.3	State of AGI in Mechatronics Today	33
1.9.4	Future Possibilities	34
1.10	Conclusion	35
1.10.1	Insights Into AGI and Mechatronics Education	36
1.10.2	Motivating Message	37
	References	38
2	Thermodynamics for Mechatronics	41
	<i>Yadav Krishnakumar Rajnath, Shrikant Tiwari and Virendra Kumar</i>	
2.1	Introduction	42
2.2	Defining Mechatronics and Its Interdisciplinary Nature	43
2.2.1	The Role of Thermodynamics in Engineering Innovation	44
2.2.2	Significance of Integrating Thermodynamics in Mechatronics	45
2.3	Fundamentals of Thermodynamics for Mechatronics	46
2.3.1	Laws of Thermodynamics: Concepts and Implications	47
2.3.2	Heat Transfer Mechanisms and Applications in Mechatronics	48
2.3.3	Energy Conversion Principles and Efficiency Considerations	50

2.4	Enhancing Efficiency in Mechatronics Through Thermodynamics	52
2.4.1	Thermodynamics-Driven Design Optimization for Mechatronic Systems	53
2.4.2	Thermal Management Strategies: Heat Dissipation and Regulation	54
2.4.3	Energy Efficiency Techniques and Heat Recovery in Mechatronics	56
2.5	Sustainability and Thermodynamics in Mechatronics	58
2.5.1	Mechatronics as a Catalyst for Sustainable Engineering	60
2.5.2	Environmental Benefits of Energy-Efficient Mechatronics	62
2.5.3	Utilizing Thermodynamics for Sustainable Resource Management	64
2.6	Innovative Applications and Future Trends	66
2.6.1	Harnessing Waste Heat: Thermoelectric Generators in Mechatronics	68
2.6.2	Embracing Energy-Frugal Systems: Future Trends and Challenges	68
2.6.3	Challenges in Implementing Future Trends	70
2.7	Educational and Professional Implications	72
2.7.1	Emphasizing the Importance of Incorporating Thermodynamics Education in Mechatronics Programs	74
2.7.2	Encouraging Interdisciplinary Collaboration Among Engineers to Optimize Energy-Frugal Mechatronic Systems	76
2.7.3	Conclusion: Leveraging Thermodynamics for Energy-Efficient Mechatronic Designs	78
	References	79
3	Role of Data Acquisition, Sensors, and Actuators in Mechatronics Industry	83
	<i>Harpreet Kaur Channi</i>	
3.1	Introduction	84
3.2	Literature Survey	86
3.3	Fundamentals of Data Acquisition	87
3.3.1	Types of Data Acquisition Systems	89
3.3.2	Analog-to-Digital Conversion	90

3.3.3	Sampling and Signal Conditioning	91
3.3.4	Sensors in Mechatronics	92
3.3.5	Actuators in Mechatronics	93
3.4	Coordination and Synchronization in Mechatronic Systems	94
3.4.1	Interplay Between Data Acquisition, Sensors, and Actuators	94
3.5	Industrial Automation and Robotics	95
3.5.1	Automotive and Transportation Systems	96
3.5.2	Healthcare and Biomedical Applications	96
3.6	Technical Challenges in Integration and Compatibility	97
3.6.1	Innovations Driving Mechatronics Advancements	98
3.6.2	Mechatronics Industry and Industry 4.0	99
3.7	Future Trends and Implications	100
3.7.1	Advancements in Sensor Technology	101
3.7.2	Integration of AI and IoT in Mechatronic Systems	101
3.8	Conclusion	102
	References	103
4	Optimization Techniques for Mechatronics: A Comprehensive Review and Future Directions	109
	<i>Ikvinderpal Singh and Sapandeep Kaur Dhillon</i>	
4.1	Introduction	110
4.1.1	Key Components of Mechatronics	110
4.2	Related Work	111
4.3	Optimization in Mechatronics Design	113
4.4	Optimization in Mechatronics Control	116
4.5	Optimization in Mechatronics Manufacturing	118
4.6	Multi-Objective Optimization in Mechatronics	121
4.7	Real-Time Optimization for Mechatronics	123
4.8	Challenges in Optimization for Mechatronics	126
4.9	Opportunities in Optimization for Mechatronics	127
4.10	Future Directions in Optimization for Mechatronics	128
4.11	Conclusion	130
	Declarations	131
	Conflict of Interest	131
	Ethics Approval and Consent to Participate	131
	Consent for Publication	131
	Competing Interests	131

Open Access	131
Funding Statement	132
References	132
5 Reinforcement Learning for Adaptive Mechatronics Systems	135
<i>D. Sathya, G. Saravanan and R. Thangamani</i>	
5.1 Introduction to Adaptive Mechatronics Systems	136
5.2 Fundamentals of Reinforcement Learning	139
5.3 Reinforcement Learning Algorithms for Mechatronics	142
5.4 Adaptive Control Strategies in Mechatronics	144
5.5 Autonomous Decision-Making in Mechatronics	147
5.6 Optimization and Energy Efficiency in Mechatronics	149
5.7 Safety and Robustness in Reinforcement Learning	153
5.8 Real-World Applications and Case Studies	155
5.9 Challenges and Future Directions	174
5.10 Ethical and Societal Implications	176
5.11 Conclusion	178
References	179
Further Reading	181
6 Application of PLC in the Mechatronics Industry	185
<i>Harpreet Kaur Channi, Pulkit Kumar and Arvind Dhingra</i>	
6.1 Introduction	186
6.1.1 History and Evolution of PLCs	188
6.1.2 Literature Review	189
6.1.3 Scope and Objectives	190
6.2 Role of PLC in Mechatronics System Integration	191
6.2.1 Integration of PLC with Mechanical Systems	193
6.2.2 Integration of PLC with Electrical Systems	193
6.2.3 Integration of PLC with Computing Systems	194
6.3 PLC Applications in Mechatronics Industry	195
6.3.1 Programming and Implementation of PLC in Mechatronics	196
6.4 PLC in Mechatronics System Design	197
6.4.1 Integration of PLCs in Mechatronics Systems	197
6.4.2 Mechatronics System Components	198
6.4.3 PLC Hardware Selection	198
6.5 Safety in Mechatronics Systems	199
6.5.1 Safety Standards and Regulations	199
6.5.2 Safety Interlocks and Emergency Stop Systems	200

6.5.3	Fault Detection and Tolerance	201
6.6	Case Studies for Mechatronics Systems Using PLCs	202
6.6.1	Automotive Manufacturing	202
6.6.2	Bottling and Packaging Industry	202
6.6.3	Aircraft Landing Gear Control	203
6.6.4	E-Commerce Warehouse Automation	203
6.6.5	CNC Machining Centers	203
6.6.6	Precision Agriculture	204
6.7	Challenges and Future Trends	204
6.7.1	Challenges in Implementing Mechatronics Systems	204
6.7.2	Emerging Technologies and Trends in Mechatronics	205
6.8	Conclusion	206
	References	207
7	Fuzzy Logic and Its Applications in Mechatronic Control Systems	211
	<i>D. Sathya, G. Saravanan and R. Thangamani</i>	
7.1	Introduction	212
7.1.1	Applications of Fuzzy Logic in Mechatronic Control Systems	214
7.2	Fuzzy Control Systems	215
7.2.1	Bridging Precision and Flexibility	215
7.2.2	Understanding Fuzzy Control Systems	216
7.2.3	Applications of Fuzzy Control Systems	217
7.2.4	Benefits and Challenges	217
7.2.5	Advantages of Fuzzy Logic in Mechatronic Control	218
7.3	Fuzzy Logic Applications in Mechatronic Control Systems	220
7.4	Fuzzy Expert Systems in Mechatronics	221
7.4.1	Enhancing Decision-Making and Control	221
7.4.2	Understanding Fuzzy Expert Systems	222
7.4.3	Applications in Mechatronics	222
7.4.4	Benefits and Challenges	223
7.5	Fuzzy Logic and Machine Learning in Mechatronics	223
7.5.1	A Synergistic Approach to Intelligent Control	223
7.5.2	Fuzzy Logic: Handling Uncertainty and Complex Relationships	224
7.5.3	Machine Learning: Data-Driven Adaptability	224
7.5.4	Applications in Mechatronics	225
7.5.5	Benefits and Challenges	226
7.6	Fuzzy Control in Multivariable Mechatronic Systems	227

7.6.1	Navigating Complexity with Adaptability	227
7.6.2	Challenges in Multivariable Mechatronic Systems	227
7.6.3	Fuzzy Control: A Multivariable Solution	227
7.6.4	Applications and Benefits	228
7.6.5	Benefits in Specific Applications	229
7.6.6	Challenges and Considerations	230
7.7	Industrial Automation and Fuzzy Logic	230
7.7.1	Enhancing Precision and Adaptability	230
7.7.2	Challenges in Industrial Automation	230
7.7.3	Fuzzy Logic: A Solution for Industrial Automation	230
7.7.4	Benefits and Considerations	232
7.8	Challenges and Future Directions	233
7.8.1	Challenges	233
7.8.2	Future Directions	234
7.9	Conclusion	235
	References	236
	Further Reading	237
8	Drones and Autonomous Robotics Incorporating Computational Intelligence	243
	<i>R. Thangamani, R. K. Suguna and G. K. Kamalam</i>	
8.1	Introduction	244
8.2	Literature Review	248
8.3	Navigation and Path Planning	252
8.4	Perception and Object Detection	258
8.5	Adaptive Control and Decision-Making	265
8.6	Swarm Robotics and Multi-Agent Systems	266
8.7	Autonomous Drone Delivery Systems	270
8.8	Human–Robot Interaction and Collaboration	277
8.9	Future Trends and Challenges	284
8.10	Ethical Implications of Autonomous Robotics and Drones	289
8.11	Conclusion	293
	References	294
9	Exploring the Convergence of Artificial Intelligence and Mechatronics in Autonomous Driving	297
	<i>Ritika Wason, Parul Arora, Vishal Jain, Devansh Arora and M. N. Hoda</i>	
9.1	Introduction	297
9.2	Key Components of Advanced Driver Systems	301

9.2.1	LiDAR (Light Detection and Ranging)	302
9.2.2	RADAR (Radio Detection and Ranging)	302
9.2.3	Ultrasonic Sensors	303
9.2.4	Video Cameras	303
9.2.5	GPS (Global Positioning System)	303
9.3	Current State of AI-Enabled Self-Driving Mechatronics	303
9.4	Challenges in Self-Driving Mechatronics	305
9.5	Advantages of Self-Driving Mechatronics	307
9.6	Self-Driving and Environmental Sustainability	308
9.7	Legal and Safety Issues in Autonomous Driving	310
9.8	Conclusion	310
9.9	Future Directions in Self-Driving Mechatronics	313
	References	313
10	Improving Power Quality for Industry Control Using Mechatronics Devices	317
	<i>Pulkit Kumar, Harpreet Kaur Channi and Surbhi Gupta</i>	
10.1	Introduction	318
10.1.1	Scope and Objectives of Power Quality in Industrial Control	320
10.1.2	Literature Review	320
10.2	Power Quality in Industrial Settings	322
10.2.1	Importance of Power Quality in Industrial Control	322
10.2.2	Challenges and Issues in Power Quality for Industrial Control	323
10.3	Mechatronics Devices for Power Quality Improvement	324
10.3.1	Applications of Mechatronics Devices in Industrial Control	326
10.3.2	Power Quality Monitoring and Analysis	326
10.3.2.1	Power Quality Parameters and Standards	326
10.3.2.2	Power Quality Monitoring Techniques	327
10.3.2.3	Data Analysis and Interpretation for Power Quality Assessment	328
10.4	Case Studies of Mechatronics Devices in Industry Control	330
10.4.1	Case Study 1	330
10.4.2	Case Study 2	331
10.4.3	Case Study 3	332
10.5	Integration of Mechatronics Devices in Industrial Control Systems	333
10.5.1	Challenges and Considerations for Integration	333

10.5.2	Communication and Control Interfaces	335
10.5.3	Safety and Reliability Aspects	336
10.6	Future Trends and Innovations in Mechatronics for Power Quality Improvement	337
10.6.1	Emerging Technologies in Mechatronics	337
10.6.2	Potential Applications in Industry Control	338
10.6.3	Implications for Power Quality Enhancement	340
10.7	Conclusion	342
	References	342
11	Study on Integrated Neural Networks and Fuzzy Logic Control for Autonomous Electric Vehicles	347
	<i>S. Boopathi</i>	
11.1	Introduction	348
11.1.1	Need for Advanced Control Systems	350
11.1.2	Objectives of the Chapter	350
11.2	Fundamentals of Neural Networks and Fuzzy Logic	351
11.2.1	Neural Networks: Concepts	351
11.2.1.1	Feedforward Neural Networks	352
11.2.1.2	Recurrent Neural Networks	352
11.2.1.3	Convolutional Neural Networks	352
11.2.2	Fuzzy Logic: Principles and Membership Functions	353
11.2.2.1	Linguistic Variables and Fuzzy Sets	353
11.2.2.2	Fuzzy Rule-Based Systems	353
11.2.2.3	Defuzzification Techniques	353
11.3	Autonomous Electric Vehicles: Challenges and Control Requirements	354
11.3.1	Control Challenges in Autonomous Electric Vehicles	354
11.3.2	Importance of Real-Time Decision-Making	355
11.3.3	Role of Computational Intelligence in Autonomous Vehicles	355
11.3.3.1	Perception and Sensing	355
11.3.3.2	Decision-Making and Control	355
11.3.3.3	Localization and Mapping	356
11.3.3.4	Adaptation and Learning	356
11.3.3.5	Safety and Verification	356
11.4	Neural Network-Based Control for Autonomous Electric Vehicles	357
11.4.1	Perception and Sensing Using Neural Networks	357
11.4.1.1	Object Detection and Recognition	358

	11.4.1.2	Sensor Fusion for Environmental Perception	358
	11.4.1.3	Semantic Segmentation	358
11.4.2		Neural Network–Based Path Planning and Navigation	358
	11.4.2.1	Lane Following and Trajectory Prediction	359
	11.4.2.2	Collision Avoidance and Emergency Braking	359
	11.4.2.3	Complex Traffic Scenarios	359
	11.4.2.4	Learning from Simulation and Real-World Data	359
	11.4.2.5	Continuous Learning and Improvement	360
11.4.3		Adaptive Learning and Self-Improvement Using Neural Networks	360
	11.4.3.1	Continuous Learning from Driving Experience	360
	11.4.3.2	Overcoming Challenging Situations Through Learning	360
	11.4.3.3	Behavior Prediction and Adaptation	361
	11.4.3.4	User-Centric Adaptation	361
	11.4.3.5	Balancing Safety and Efficiency	361
11.5		Fuzzy Logic Control for Energy-Efficient Driving	361
	11.5.1	Fuzzy Logic–Based Energy Management	361
	11.5.1.1	Battery State-of-Charge Control	362
	11.5.1.2	Optimal Power Distribution for Efficiency	362
	11.5.1.3	Dynamic Load Management	362
	11.5.1.4	User Preferences and Adaptive Control	362
	11.5.1.5	Integration with Traffic and Route Information	363
	11.5.2	Fuzzy Logic–Based Adaptive Cruise Control	363
	11.5.2.1	Following Distance Regulation	363
	11.5.2.2	Traffic Scenario Adaptation	363
	11.5.2.3	Comfort and Driver Behavior Consideration	364
	11.5.2.4	Handling Non-Motorized Traffic	364
	11.5.2.5	Cooperative Adaptive Cruise Control	364
	11.5.3	Fuzzy Logic–Based Regenerative Braking	365
	11.5.3.1	Brake Force Modulation	365

	11.5.3.2	Adaptive Braking Intensity	365
	11.5.3.3	User Preferences and Driving Conditions	365
	11.5.3.4	Predictive Braking	366
	11.5.3.5	Coordination with Traffic Flow	366
11.5.4		Fuzzy Logic–Based Brake Force Optimization for Maximizing Energy Recuperation	366
	11.5.4.1	Fuzzy Control of Brake Force	366
	11.5.4.2	Balancing Energy Recuperation and Safety	367
	11.5.4.3	Predictive Energy Management	367
	11.5.4.4	User Preferences and Adaptive Control	367
	11.5.4.5	Real-Time Adaptation	367
11.6		Integration of Neural Networks and Fuzzy Logic for Enhanced Autonomy	367
	11.6.1	Combined Perception and Control using Neural-Fuzzy Systems	367
	11.6.1.1	Enhanced Perception	368
	11.6.1.2	Adaptive Decision-Making	368
	11.6.1.3	Human-Like Reasoning	368
	11.6.1.4	Autonomous Learning and Improvement	368
	11.6.1.5	Real-Time Adaptation	369
11.6.2		Decision Fusion for Improved Safety and Reliability	369
	11.6.2.1	Multi-Sensor Data Fusion	370
	11.6.2.2	Multi-Model Decision-Making	370
	11.6.2.3	Confidence-Based Decision Fusion	370
	11.6.2.4	Handling Uncertain Situations	370
	11.6.2.5	Redundancy and Fault Tolerance	370
11.6.3		Multi-Objective Optimization Using Hybrid Approaches	371
	11.6.3.1	Multi-Objective Decision Formulation	371
	11.6.3.2	Pareto Front Exploration	371
	11.6.3.3	User-Centric Optimization	371
	11.6.3.4	Real-Time Adaptation	372
	11.6.3.5	Ethical and Safety Considerations	372
11.7		Case Studies and Applications	372
	11.7.1	Autonomous Electric Fleet Management	372
	11.7.1.1	Traffic Flow Optimization	373
	11.7.1.2	Dynamic Route Planning	373

11.7.2	Urban Mobility Solutions and Ride-Sharing	373
11.7.2.1	User Experience Enhancement	373
11.7.2.2	Fleet Utilization Optimization	373
11.8	Future Prospects and Challenges	374
11.8.1	Ethical and Legal Considerations	374
11.8.2	Scalability and Real-World Deployment Challenges	374
11.8.3	Emerging Trends in Control and Autonomy	374
11.9	Conclusions	375
	List of Abbreviations	375
	References	375
12	Advancing Mechatronics Through Artificial Intelligence	381
	<i>Pawan Whig, Jhansi Bharathi Madavarapu, Venugopal Reddy Modhugu, Balaram Yadav Kasula and Ashima Bhatnagar Bhatia</i>	
12.1	Introduction	381
12.1.1	Background and Motivation	382
12.1.2	Scope and Objectives of the Chapter	382
12.2	Foundations of Mechatronics and Artificial Intelligence	386
12.2.1	Mechatronics: Where Physicality Meets Computation	386
12.2.2	Artificial Intelligence: Pinnacle of Machine Cognition	387
12.2.3	Confluence of Forces: Cognitive Integration	387
12.2.4	Toward Intelligent Autonomy	387
12.3	Synergies Between Artificial Intelligence and Mechatronics	388
12.3.1	Enhanced Adaptability Through AI	388
12.3.2	Real-Time Decision-Making and Control	389
12.3.3	Cognitive Robotics and Autonomous Systems	389
12.3.4	Breaking Boundaries in Smart Manufacturing	390
12.4	Case Studies: AI-Driven Advances in Mechatronics	390
12.4.1	Smart Manufacturing and Industrial Automation	391
12.4.2	Self-Learning Robotic Systems	391
12.4.3	Predictive Maintenance and Prognostics	392
12.4.4	Autonomous Vehicles: A Driving Force	392
12.5	Challenges and Opportunities	392
12.5.1	Technical Challenges: Reliability and Safety	393
12.5.2	Ethical Considerations: Accountability and Transparency	393

12.5.3	Collaborative Intelligence: Human–Machine Interaction	394
12.5.4	Opportunities for Innovation and Progress	394
12.6	Future Directions and Trends	395
12.6.1	AI-Enabled Mechatronic Innovations	395
12.6.2	Collaborative Intelligence in Human–Machine Systems	395
12.6.3	Ethical and Responsible AI in Mechatronics	396
12.6.4	Empowering Edge Computing	397
12.7	Conclusion	397
12.8	Future Scope	398
	References	398
13	Computational Intelligent Techniques in Mechatronics: Emerging Trends and Case Studies	401
	<i>Anita Mohanty, Ambarish G. Mohapatra, Subrat Kumar Mohanty, Bright Keswani and Sasmita Nayak</i>	
13.1	Introduction to Mechatronics and Computational Intelligence	402
13.1.1	Outline of Mechatronics and Its Interdisciplinary Nature	402
13.1.2	Introduction to Computational Intelligence Techniques	402
13.1.3	Importance of CI in Solving Mechatronics Challenges	403
13.2	Artificial Neural Networks (ANNs) in Mechatronics	403
13.2.1	Fundamentals of Artificial Neural Networks	404
13.2.2	Applications of ANNs in Mechatronic System Modeling	405
13.2.3	ANN-Based Control in Mechatronic Systems	406
13.2.4	Case Studies: ANNs for Robotic Control and Fault	406
13.3	Reinforcement Learning in Mechatronics	407
13.3.1	Introduction to Reinforcement Learning (RL)	408
13.3.2	RL Algorithms and Their Applications in Mechatronics	409
13.3.3	RL for Autonomous Systems and Decision-Making	410
13.3.4	Case Studies: Reinforcement Learning in Autonomous Vehicles	411
13.4	Evolutionary Algorithms for Mechatronic System Design	412
13.4.1	Genetic Algorithms and Their Optimization Applications	414

13.4.2	Evolutionary Strategies in Mechatronics	415
13.4.3	Multi-Objective Optimization with Evolutionary Algorithms	416
13.4.4	Case Studies: Evolutionary Algorithms for Mechatronic Design	418
13.5	Emerging Trends in Mechatronics with Computational Intelligence	419
13.5.1	Integration of AI and CI in Mechatronics	421
13.5.2	Explainable AI in Safety-Critical Mechatronic Systems	422
13.5.3	Human–Robot Interaction and Emotional Intelligence	424
13.5.4	Biologically Inspired Robotics and Soft Robotics	425
13.5.5	Swarm Intelligence for Mechatronic System Control	426
13.6	Real-World Case Studies	427
13.6.1	Case Study 1: Adaptive Control of a Mechatronic System Using ANNs	427
13.6.2	Case Study 2: Reinforcement Learning for Autonomous Drone Navigation	429
13.6.3	Case Study 3: Multi-Objective Optimization in Mechatronic Design	433
13.6.4	Case Study 4: Explainable AI for Fault Diagnosis in a Robotic Arm	435
13.6.5	Case Study 5: Emotional Intelligence in a Social Robot	437
13.7	Conclusion	439
13.7.1	Recapitulation of Emerging Trends in CI for Mechatronics	439
13.7.2	Future Directions and Potential Applications	440
13.7.3	Implications of Computational Intelligent Techniques in Mechatronics Advancements	440
13.7.4	Key Impacts of CI in Mechatronics	440
	References	441
14	Advanced Sensing Systems in Automobiles: Computational Intelligence Approach	445
	<i>Mamta B. Savadatti and Ajay Sudhir Bale</i>	
14.1	Introduction	445
14.2	Computational Intelligence Approach	447
14.2.1	Sensor Technology	447

14.2.1.1	Sensor Units Within the Automobile	448
14.2.1.2	In-Vehicle Sensors	449
14.2.1.3	Transport Networks with Intelligence	451
14.2.2	UAV Sensors in Remote Automobile Sensing	452
14.2.2.1	WSN for City Traffic Control System	452
14.2.3	The Video Intelligent Car Using WSN	455
14.2.4	Effects of CO ₂ Inside Cars	457
14.2.5	Accident Prevention In-Vehicle Air Quality	459
14.2.6	Sensors for Weather and Obstacle Detection in Vehicles	461
14.3	Methodology	463
14.3.1	Traditional In-Car Eye Blink Detection	463
14.3.2	Proposed Methodology	465
14.4	Conclusions	466
	References	467
15	Design of Arduino UNO–Based Novel Multi-Featured Robot	471
	<i>Jaspinder Kaur, Rohit Anand, Nidhi Sindhwani, Ajay Kumar Sharma and Vishal Jain</i>	
15.1	Introduction	472
15.2	Design Implementation	473
15.2.1	Microcontroller	473
15.2.2	Motor Driver	474
15.2.3	Bluetooth	475
15.2.4	Ultrasonic Sensor	475
15.2.5	Servomotor	476
15.2.6	PIR Sensor	476
15.2.7	Components Specifications	477
15.3	Proposed Model	477
15.4	Process and Working Methodology	478
15.5	Experiment and Applications	482
15.6	Conclusion	484
15.7	Future Scope	485
	Acknowledgments	485
	References	485
16	Integrating Mechatronics in Autonomous Agricultural Machinery: A Case Study	491
	<i>N. V. Suresh, Ananth Selvakumar, Gajalakshmi Sridhar and Vishal Jain</i>	
16.1	Introduction	492

16.2	Case Background	493
16.3	Literature Review	495
16.3.1	Agribusiness and Mechatronics	495
16.3.2	Robotization and Exactness Developing	496
16.3.3	Sensors and Data Acquisition	496
16.3.4	Systems of Automation and Control	496
16.3.5	Normal Impact and Acceptability	496
16.3.6	Troubles and Future Headings	496
16.4	Methodology	496
16.5	Implementation	498
16.6	Findings	501
16.7	Suggestion	502
16.8	Conclusion	504
	References	505
	Index	509

Preface

Mechatronics has been a revolutionary force in engineering and medical robotics over the past decade. It will lead to a major industrial revolution and affect research in every field of engineering. This book covers the basics of mechatronics, computational intelligence approaches, simulation and modeling concepts, architectures, nanotechnology, real-time monitoring and control, different actuators, and sensors. This resource is important for research and development departments in academia, government, and industry, and as a reference source in university libraries. This book explains clearly and comprehensively the engineering design process at different stages. As the historical divisions between the various branches of engineering and computer science become less clearly defined, mechatronics may provide a roadmap for nontraditional engineering students studying within the traditional university structure. This book covers all the algorithms and techniques found in mechatronics engineering, well explained with real-time examples, especially lab experiments that will be very informative to students and scholars.

Chapter 1 of this book provides an overview of promising AI approaches for modern mechatronics, along with the key benefits. The second chapter discusses classical thermodynamics and heat transfer principles that can optimize the blueprint, performance, and regulation of mechatronic apparatus.

Chapter 3 explores the role of data acquisition, sensors, and actuators in the mechatronics industry, while Chapter 4 discusses the challenges and opportunities in employing these techniques. Furthermore, it proposes future research directions to optimize mechatronic systems.

Chapter 5 highlights the potential of RL for the future of adaptive mechatronics, fostering a new era of intelligent and versatile systems that can adapt, learn, and excel in diverse and dynamic scenarios. The sixth chapter shows a study of how important PLCs are to advancing the mechatronics sector and enabling more advanced forms of industrial automation.

Chapter 7 discusses fuzzy logic and its applications in mechatronic control systems, while Chapter 8 highlights the need for addressing ethical

considerations and ensuring responsible deployment for the widespread acceptance and success of autonomous systems in the real world. Chapter 9 explores this intersection by considering the key components, challenges, and benefits of integrating AI in self-driving transportation systems. This section also highlights the advancements made in the field, current state of the art, and potential future directions.

Chapter 10 illustrates how mechatronics-based power quality solutions have increased industrial productivity, and may result in smart and strong industrial infrastructures. The eleventh chapter delves into prospects, challenges, and emerging trends, underscoring the potential of neural networks and fuzzy logic to shape the future of autonomous electric transportation.

Chapter 12 explores the transformative impact of integrating artificial intelligence (AI) techniques within the field of mechatronics, showcasing the synergistic potential that emerges when advanced AI technologies are harnessed to enhance the functionality, adaptability, and intelligence of mechatronic systems. Then, Chapter 13 delves into the intriguing area of human-robot interaction and emotional intelligence, showcasing how AI enhances interaction and emotional understanding between humans and machines.

Chapter 14 proposes a way by which a driver can be alerted to drowsiness in order to reduce the numbers of road accidents, while Chapter 15 proposes the model of a multi-featured robot that can send live surveillance and notifications if human motion is detected. Finally, Chapter 16 highlights the latency of mechatronics in altering the current agriculture practices including productivity, and sustainability.

In conclusion, we offer our heartfelt thanks to all the contributors who have made this book a reality. Your expertise, dedication, and passion have enriched every page, creating a comprehensive and insightful collection. Without your valuable insights and commitment to excellence, this project would not have been possible. Your contributions have not only elevated the quality of this book but have also left a lasting impact on the field. Additionally, we have greatly appreciated the dedicated support and valuable assistance rendered by Martin Scrivener and the Scrivener Publishing team during the publication of this volume.

Editors

**Kolla Bhanu Prakash
Satish Kumar Peddapelli
Ivan C. K. Tam
Wai Lok Woo
Vishal Jain**

AI in Mechatronics

Vansh Gehlot* and Prashant Singh Rana

Thapar Institute of Engineering and Technology, Patiala, Punjab, India

Abstract

The chapter “AI in Mechatronics” provides a comprehensive overview of how artificial intelligence (AI) techniques can enhance mechatronic systems; it covers core AI approaches, including machine learning, computer vision, soft computing methods, natural language processing, AI planning, and intelligent system design tools. Key real-world applications across areas like manufacturing automation, robotics, vehicles, and human–machine interaction are analyzed. The integration of data-driven and knowledge-based AI methods can endow mechatronics with advanced capabilities around autonomy, environmental perception, reasoning, control, and human collaboration. This creates intelligent self-optimizing systems that continue learning and adapting. Current challenges around model accuracy, data availability, security, and algorithmic transparency are discussed along with emerging opportunities in embedded intelligence and bio-inspired robotics. Overall, the synergistic fusion of AI and mechatronics promises to transform technological systems across industrial and societal domains by enhancing automation, augmenting human capabilities, and enabling next-generation smart mechanized assistants.

Keywords: Machine learning, human–robot collaboration, computer vision, robotic systems, natural language processing, manufacturing automation, self-driving vehicles

*Corresponding author: gehlotvansh111@gmail.com

1.1 Introduction to AI Techniques for Mechatronics

Mechatronics refers to the synergistic integration of mechanical, electrical, and computer engineering to design smart systems and products capable of exhibiting both information-processing and physical-action capabilities. It combines the core disciplines of mechanics, electronics, control systems, and computing to create high-performance systems with built-in intelligence.

Although mechatronics has its origins in industrial robotics and manufacturing automation, it has grown tremendously in scope and adoption over the past few decades. Today, mechatronic systems and principles are utilized in a diverse range of applications including automotive systems, aerospace systems, industrial production systems, defense systems, material handling systems, healthcare systems, and consumer product design. Figure 1.1 shows the flowchart depicting the design methodology for mechatronics systems, mechatronics integrates various engineering disciplines.

Modern mechatronic systems incorporate sensors, actuators, microprocessors, control systems, and mathematical modeling into product design. This facilitates features like automation, precision, efficiency, adaptability, reconfigurability, safety, reliability, and productivity. For example, an automated robotic manufacturing system may use servo motors and drives for motion control, various sensors for inspection and feedback, PLCs or microcontrollers for regulated actuation and monitoring, and sophisticated control software for supervision, analysis, and coordination [1].

With rapid advances in artificial intelligence (AI) and machine learning, integrating AI techniques into mechatronic systems has become an active area of innovation and research. AI can endow mechatronics with higher levels of intelligence, autonomy, perception, and decision-making capabilities to create smart, self-optimizing systems. This introductory chapter provides an overview of promising AI approaches for modern mechatronics along with the key benefits.

1.1.1 Overview of Key AI Approaches

Several AI techniques hold promise for advancing mechatronics.

- **Machine Learning:** This allows systems to automatically learn and improve from data without being explicitly programmed. Algorithms identify patterns and build models based on training data. Supervised, unsupervised, and reinforcement learning methods can be used for tasks like prediction, classification, and control optimization in mechatronic systems.

- Sensor fusion techniques, 151
- Sensor hub, 273
- Sensor units, 450
- Sensors, 50, 51, 52, 56, 57, 67, 69, 83–92, 94–97, 186, 187, 192, 193, 197, 198, 201, 202, 203, 204, 206, 303, 492–494, 496–505
- Sentiment analysis, 246, 280, 280
- Servomotor, 471, 476–480
- Signal, 495, 499, 500
- Signal processing, 245
- Simultaneous localization and mapping (SLAM), 10, 244, 254
- Single-shot MultiBox detector, 262, 263
- Smart cities, 261
- Smart manufacturing, 381
- Social cues and expressions, 278
- Soft actor-critic, 143
- Soft computing, 13–16, 23
- SONAR, 465, 475
- Speeded-up robust features (SURF), 262
- State of charge (SoC), 362, 363, 365, 366
- Stereo vision, 275
- Stigmergy, 267
- Structural optimization, 113, 116
- Superintelligent systems, 288
- Supervised learning, 5–7, 23
- Supervised learning, unsupervised learning, 246
- Supply chain optimization, 119, 121
- Surveillance and security, 257
- Sustainability, 41–48, 52–54, 59, 60, 62, 65–70, 73, 74–82, 83, 84, 98–103, 308
- Swarm intelligence, 13–15, 23, 402–403, 426–427, 440
- Symbolic reasoning, 31, 33
- Targeted exploration, 257
- Task allocation and scheduling, 283
- Task execution, 266, 283
- Technology readiness level (TRL), 292
- Temperature, 47–52, 55, 56, 68, 83, 84, 85, 87, 90–92
- Tesla (Nvidia), 304
- Text-to-speech (TTS), 280
- Thermal interface materials (TIMs), 55
- Thermoelectric generators, 41, 42, 57, 68
- Time-of-flight (ToF), 275
- Traffic congestion, 447, 450, 460
- Traffic control, 447, 454
- Trajectory, 222
- Trajectory planning and optimization, 116
- Transfer learning, 30, 33, 34, 36, 154, 175
- Transportation, 61, 63, 65, 66
- Transportation system, 449
- Trust region policy optimization, 142, 143
- Ultrasonic, infrared, 276
- Uncertainty and variability, 249
- Underground mining, 269
- Unmanned aerial vehicle (UAV), 270
- Unsupervised learning, 5, 6, 7, 8, 22
- User studies and feedback, 282
- User-friendly, 281, 282, 283
- Vagueness, 212
- Vehicles, 196, 200, 206
- Virtual prototyping, 21, 25
- Voltage fluctuations, 318, 323, 325, 327, 330, 332, 333, 338, 342
- Voltage regulators, 317, 320, 326
- Voltage stability, 319–322, 330, 332
- Warehouse management, 269
- Waste reduction, 287

Waymo, 304

Weigh-in-motion, 454

Weighted sum method, 122

W-UTMS, 456

You only look once, 263

ZigBee, 456

Zoox (Amazon), 305

Also of Interest

Check out these published and forthcoming titles in the “Next-Generation Computing and Communication Engineering” series from Scrivener Publishing

Computational Intelligent Techniques in Mechatronics

Edited by Kolla Bhanu Prakash, P. Satish Kumar, Ivan C. K. Tam, Wai Lok Woo and Vishal Jain

Published 2024. ISBN 978-1-394-17464-5

Machine Learning for Industrial Applications

By Kolla Bhanu Prakash

Published 2024. ISBN 978-1-394-26896-2

Machine Learning Paradigm for Internet of Things Applications

Edited by Shalli Rani, R. Maheswar, G. R. Kanagachidambaresan, Sachin Ahuja and Deepali Gupta

Published 2022. ISBN 978-1-119-76047-4

Data Science Handbook

A Practical Approach

By Kolla Bhanu Prakash

Published 2022. ISBN 978-1-119-85732-7

Digitization of Healthcare Data Using Blockchain

Edited by T. Poongodi, D. Sumathi, B. Balamurugan and K. S. Savita

Published 2022. ISBN 978-1-119-79185-0

Medical Imaging and Health Informatics

Edited by Tushar H Jaware, K Sarat Kumar, Svetlin Antonov, and Ravindra D Badgujar

Published 2022. ISBN 978-1-119-81913-4

Advanced Analytics and Deep Learning Models

Edited by Archana Mire, Shaveta Malik and Amit Kumar Tyagi

Published 2022. ISBN 978-1-119-79175-1

Integration of Renewable Energy Sources with Smart Grids

Edited by A. Mahaboob Subahani, M. Kathiresh

and G. R. Kanagachidambaresan

Published 2021. ISBN 978-1-119-75042-0

Cognitive Engineering for Next Generation Computing

A Practical Analytical Approach

Edited by Kolla Bhanu Prakash, G.R. Kanagachidambaresan, V. Srikanth
and E. Vamsidhar

Published 2021. ISBN 978-1-119-71108-7

Role of Edge Analytics on Sustainable Smart City Development

Edited by G.R. Kanagachidambaresan

Published 2020. ISBN 9781119681281

www.scrivenerpublishing.com