

# **Artificial Intelligence in Industrial Decision Making, Control and Automation**

International Series on  
**MICROPROCESSOR-BASED AND  
INTELLIGENT SYSTEMS ENGINEERING**

---

**VOLUME 14**

---

*Editor*

Professor S. G. Tzafestas, *National Technical University, Athens, Greece*

*Editorial Advisory Board*

Professor C. S. Chen, *University of Akron, Ohio, U.S.A.*

Professor T. Fokuda, *Nagoya University, Japan*

Professor F. Harashima, *University of Tokyo, Tokyo, Japan*

Professor G. Schmidt, *Technical University of Munich, Germany*

Professor N. K. Sinha, *McMaster University, Hamilton, Ontario, Canada*

Professor D. Tabak, *George Mason University, Fairfax, Virginia, U.S.A.*

Professor K. Valavanis, *University of Southern Louisiana, Lafayette, U.S.A.*

# Artificial Intelligence in Industrial Decision Making, Control and Automation

*edited by*

**SPYROS G. TZAFESTAS**

*Department of Electrical and Computer Engineering,  
National Technical University of Athens,  
Athens, Greece*

and

**HENK B. VERBRUGGEN**

*Department of Electrical Engineering,  
Delft University of Technology,  
Delft, The Netherlands*



SPRINGER-SCIENCE+BUSINESS MEDIA, B.V.

## Library of Congress Cataloging-in-Publication Data

Artificial intelligence in industrial decision making, control, and automation / edited by Spyros G. Tzafestas and Henk B. Verbruggen. p. cm. -- (International series on microprocessor-based and intelligent systems engineering ; v. 14)

Includes index.

ISBN 978-94-010-4134-8 ISBN 978-94-011-0305-3 (eBook)

DOI 10.1007/978-94-011-0305-3

1. Decision support systems. 2. Intelligent control systems. 3. Automation. 4. Artificial intelligence. I. Tzafestas, S. G., 1939-. II. Verbruggen, H. B. III. Series.

T58.62.A78 1995

658.4'03--dc20

94-46547

ISBN 978-94-010-4134-8

---

*Printed on acid-free paper*

All Rights Reserved

© 1995 Springer Science+Business Media Dordrecht

Originally published by Kluwer Academic Publishers in 1995

Softcover reprint of the hardcover 1st edition 1995

No part of the material protected by this copyright notice may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without written permission from the copyright owner.

# CONTENTS

Preface .....	xxv
Contributors .....	xxvii

## **PART 1 GENERAL ISSUES**

### **CHAPTER 1 ARTIFICIAL INTELLIGENCE IN INDUSTRIAL DECISION MAKING, CONTROL AND AUTOMATION: AN INTRODUCTION**

**S. Tzafestas and H. Verbruggen**

1. Introduction .....	1
2. Decision Making, Control and Automation .....	2
2.1. Decision Making Theory .....	2
2.2. Control and Automation .....	4
3. Artificial Intelligence Methodologies.....	6
3.1 Reasoning under uncertainty.....	7
3.2 Qualitative reasoning .....	14
3.3 Neural nets reasoning.....	16
4. Artificial Intelligence in Decision Making.....	19
5. Artificial Intelligence in Control and Supervision .....	22
6. Artificial Intelligence in Engineering Fault Diagnosis.....	24
7. Artificial Intelligence in Robotic and Manufacturing Systems.....	26
8. Conclusions .....	30
References.....	31

## CHAPTER 2

### CONCEPTUAL INTEGRATION OF QUALITATIVE AND QUANTITATIVE PROCESS MODELS

E. A. Woods

1. Introduction .....	41
2. Qualitative Reasoning.....	42
2.1. Common Concepts .....	43
2.2. Qualitative Mathematics.....	44
2.3. The notion of state .....	45
2.4. Describing Behaviour .....	45
2.5. Components of qualitative reasoning .....	45
2.6. Towards more quantitative models.....	47
3. Formal Concepts and Relations in the HPT .....	48
3.1. Quantities.....	48
3.2. Physical Objects, process equipment, materials and substances .....	48
3.3. The input file .....	49
3.4. Activity conditions .....	49
3.5. Numerical functions and influences .....	50
3.6. Logical relations and rules.....	52
4. Defining Views and Phenomena .....	52
4.1. Individuals and individual conditions.....	52
4.2. Quantity conditions and preconditions .....	54
4.3. Relations .....	56
4.4. Dynamic influences .....	56
4.5. Instantiating a definition.....	57
4.6. Activity levels.....	57
5. Deriving and Reasoning with an HPT Model .....	59
5.1. Extending the topological model.....	59
5.2. Deriving the phenomenological model.....	60
5.3. Activity and state space models.....	61
6. Discussion and Conclusion.....	63
References .....	64

**CHAPTER 3****TIMING PROBLEMS AND THEIR HANDLING AT SYSTEM INTEGRATION****L. Motus**

1. Introduction .....	67
2. Essential Features of Control Systems .....	68
2.1. Essential (forced) concurrency .....	70
2.2. Truly asynchronous mode of execution of interacting processes.....	70
2.3. Time-selective interprocess communication .....	71
3. Concerning Time-Correct Functioning of Systems.....	71
3.1. Performance-bound properties .....	72
3.2. Timewise correctness of events and data .....	72
3.3. Time correctness of interprocess communication .....	73
4. A Mathematical Model for Quantitative Timing Analysis (Q-Model) .....	73
4.1. Paradigms used .....	74
4.2. The Q-model.....	74
5. The Q-Model Based Analytical Study of System Properties .....	76
5.1. Separate elements of a specification.....	76
5.2. Pairs of interacting processes .....	77
5.3. Group of interacting processes .....	78
6. An example of the Q-Model Application .....	79
7. Conclusions .....	85
References .....	85

**CHAPTER 4****ANALYSIS FOR CORRECT REASONING IN INTERACTIVE MAN ROBOT SYSTEMS: DISJUNCTIVE SYLLOGISM WITH MODUS PONENS AND MODUS TOLLENS****E. C. Koenig**

1. Introduction .....	89
2. Valid Command Arguments.....	90

3. Correct Reasoning: Disjunctive Syllogism..... 91  
    3.1. Plausible composite command arguments..... 92  
    3.2. Plausible composite commands..... 92  
4. Conclusions ..... 96  
    References ..... 96

**PART 2**  
**INTELLIGENT SYSTEMS**

**CHAPTER 5**  
**APPLIED INTELLIGENT CONTROL SYSTEMS**  
**R. Shoureshi, M. Wheeler and L. Brackney**

1. Introduction ..... 101  
2. A Proposed Structure for Intelligent Control Systems (ICS) ..... 102  
3. Intelligent Automatic Generation Control (IAGC) ..... 105  
4. Intelligent Comfort Control System ..... 110  
5. Control System Development..... 111  
6. Experimental Results ..... 116  
7. Conclusion ..... 116  
    References ..... 119

**CHAPTER 6**  
**INTELLIGENT SIMULATION IN DESIGNING COMPLEX DYNAMIC CONTROL SYSTEMS**  
**F. Zhao**

1. Introduction..... 127  
2. The Control Engineer’s Workbench..... 128



3. Automatic Control Synthesis in Phase Space.....	128
3.1. Overview of the phase space navigator .....	129
3.2. Intelligent navigation in phase space.....	129
3.3. Planning control paths with flow pipes .....	130
4. The Phase Space Navigator .....	131
4.1. Reference trajectory generation.....	131
4.2. Reference trajectory tracking.....	133
4.3. The autonomous control synthesis algorithms .....	135
4.4. Discussion of the synthesis algorithms.....	137
5. An illustration: Stabilizing a Buckling Column .....	139
5.1. The column model.....	140
5.2. Extracting and representing qualitative phase-space structure of the buckling column .....	141
5.3. Synthesizing control laws for stabilizing the column.....	143
5.4. The phase-space modeling makes the global navigation possible .....	148
6. An application: Maglev Controller Design .....	148
6.1. The maglev model .....	148
6.2. Phase-space control trajectory design.....	150
7. Discussions .....	155
8. Conclusions .....	155
References .....	156

## CHAPTER 7

### MULTIRESOLUTIONAL ARCHITECTURES FOR AUTONOMOUS SYSTEMS WITH INCOMPLETE AND INADEQUATE KNOWLEDGE REPRESENTATION

#### A. Meystel

1. Introduction .....	159
2. Architectures for Intelligent Control Systems: Terminology, Issues, and a Conceptual Framework.....	161
2.1. Definitions .....	161
2.2. Issues and problems.....	165

2.3. Conceptual framework for intelligent systems architecture.....	170
3. Overview of the General Results.....	171
4. Evolution of the Multiresolutional Control Architecture (MCA): Its Active and Reactive Components .....	173
4.1. General structure of the controller.....	173
4.2. Multiresolutional control architecture (MCA) .....	175
5. Nested Control Strategy: Generation of a Nested Hierarchy for MCA.....	177
5.1. GFACS triplet: Generation of intelligent behavior .....	177
5.2. Off-line decision making procedures of planning-control in MCA .....	178
5.3. Generalised controller.....	180
5.4. Universe of the trajectory generator: Second level .....	181
5.5. Representation of the planning/control problem in MCA .....	183
5.6. Search as the general control strategy for MCA .....	185
6. Elements of the Theory of Nested Multiresolutional Control for MCA .....	187
6.1. Commutative diagram for a nested multiresolutional controller.....	187
6.2. Tessellated knowledge bases .....	187
6.3. Generalization.....	188
6.4. Attention and consecutive refinement .....	189
6.5. Accuracy and resolution of representation .....	190
6.6. Complexity and tessellation: $\epsilon$ -entropy.....	194
7. MCA in Autonomous Control System .....	195
7.1. The multiresolutional generalization of system models.....	195
7.2. Perception stratified by resolution.....	196
7.3. Maps of the world stratified by resolution.....	197
8. Development of Algorithms for MCA .....	198
8.1. Extensions of the Bellman's optimality principle .....	198
8.2. Nested Multiresolutional search in the state space.....	198
9. Complexity of Knowledge Representation and Manipulation .....	201
9.1. Multiresolutional consecutive refinement: Search in the state space .....	201
9.2. Multiresolutional consecutive refinement: Multiresolutional search of a trajectory in the state space.....	203
9.3. Evaluation and minimization of the complexity of the MCA .....	205
10. Case Studies.....	208
10.1 A pilot for an autonomous robot (two levels of resolution).....	208

10.2 PILOT with two agents for control (a case of behavioral duality) .....	211
11. Conclusion .....	219
References .....	220

## **CHAPTER 8**

### **DISTRIBUTED INTELLIGENT SYSTEMS IN CELLULAR ROBOTICS**

**T. Fukuda, T. Ueyama and K. Sekiyama**

1. Introduction .....	225
2. Concept of Cellular Robotic System .....	226
3. Prototypes of CEBOT .....	227
3.1. Prototype CEBOT Mark IV .....	229
3.2. Cellular Manipulator .....	231
4. Distributed Genetic Algorithm .....	234
4.1. Distributed Decision Making .....	234
4.2. Structure configuration problem .....	235
4.3. Application of genetic algorithm .....	236
4.4. Distributed genetic algorithm .....	239
4.5. Simulation results .....	241
5. Conclusions .....	245
References .....	245

## **CHAPTER 9**

### **DISTRIBUTED ARTIFICIAL INTELLIGENCE IN MANUFACTURING CONTROL**

**S. Albayrak and H. Krallmann**

1. Introduction .....	247
2. Tasks of Manufacturing Control .....	248
3. The State-of-the-Art of the DAI Technique in Manufacturing Control .....	252
3.1. ISIS/OPIS .....	252

3.2. SOJA/SONIA .....	254
3.3. YAMS.....	255
4. Distributed Artificial Intelligence.....	259
4.1. Cooperative problem solving.....	261
4.2. Phases of cooperating problem solving .....	261
4.3. Blackboard metaphor, model and frameworks.....	264
4.4. History of the blackboard model .....	274
4.5. Advantages of DAI.....	276
5. VerFlex - BB System: Approach and Implementation.....	277
5.1. Distributed approach to the solution of the task order execution .....	277
5.2. Why was the blackboard model used? .....	281
5.3. The VerFlex - BB system.....	281
References .....	292

## **PART 3**

### **NEURAL NETWORKS IN MODELLING, CONTROL AND SCHEDULING**

#### **CHAPTER 10**

##### **ARTIFICIAL NEURAL NETWORKS FOR MODELLING**

**A.J. Krijgsman, H.B. Verbruggen and P.M. Bruijn**

1. Introduction .....	297
2. Description of artificial neurons .....	298
3. Artificial neural networks (ANN).....	299
4. Nonlinear models and ANN .....	300
5. Networks.....	302
5.1. Multilayered static neural networks .....	302
5.2. Radial basis function networks.....	303
5.3. Cerebellum model articulation controller (CMAC) .....	304
6. Identification of Dynamic Systems Using ANN.....	306

6.1. Identification problem definition.....	306
6.2. Model description for identification.....	308
7. Hybrid Modelling .....	308
Orthogonal least-squares algorithm.....	309
8. Model Validation.....	313
9. Experiments and Results Using Neural Identification .....	314
10. Conclusions .....	323
References .....	323

## **CHAPTER 11**

### **NEURAL NETWORKS IN ROBOT CONTROL**

**S.G. Tzafestas**

1. Introduction .....	327
2. Neurocontrol Architectures .....	328
2.1. General issues.....	328
2.2. Unsupervised NN control architectures.....	329
2.3. DIMA II. Neurocontroller for linear systems.....	331
2.4. Adaptive learning neurocontrol for CARMA systems.....	336
3. Robot Neurocontrol .....	339
3.1. A look at robotics .....	339
3.2. Neural nets in robotics: General review .....	341
3.3. Robot control using hierarchical NNs .....	343
3.4. Minimum torque-change robot neurocontrol .....	346
3.5. Improved iterative learning robot neurocontroller .....	349
4. Numerical Examples.....	352
4.1. Example 1: DIMA II controller for linear systems.....	352
4.2. Example 2: Neurocontroller for CARMA systems .....	354
4.3. Example 3: Supervised neurocontrol of a broom - balancing system .....	357
4.4. Example 4: Feedback - error learning robot neurocontrol .....	361
4.5. Example 5: Iterative robot neurocontrol.....	366
4.6. Example 6: Unsupervised robot-neurocontroller using hierarchical NN .....	372
5. Conclusions and Discussion .....	375

6. Appendix: A Brief Look at Neural Networks .....	376
6.1. Single - layer perceptron (SLP) .....	377
6.2. Multi - layer perceptron (MLP) .....	378
6.3. Hopfield network .....	381
References .....	384

## **CHAPTER 12**

### **CONTROL STRATEGY OF ROBOTIC MANIPULATOR BASED ON FLEXIBLE NEURAL NETWORK STRUCTURE**

**M. Teshnehlab and K. Watanabe**

1. Introduction .....	389
2. The Representation of Bipolar Unit Function .....	390
3. Learning Architecture .....	391
3.1. The learning of connection weights .....	392
3.2. The learning of sigmoid unit function parameters .....	393
4. Neural Network - Based Adaptive Controller .....	394
4.1. The feedback - error learning rule .....	396
4.2. Adaptation of neural network controller .....	396
5. Simulation Example .....	397
6. Conclusion .....	402
References .....	402

## **CHAPTER 13**

### **NEURO - FUZZY APPROACHES TO ANTICIPATORY CONTROL**

**L.H. Tsoukalas, A. Ikonopoulos and R.E. Uhrig**

1. Introduction .....	405
2. Issues of Formalism Anticipatory Systems .....	407
3. Issues of Measurement and Prediction .....	412
4. Conclusions .....	417
References .....	418

**CHAPTER 14****NEW APPROACHES TO LARGE - SCALE SCHEDULING PROBLEMS:  
CONSTRAINT DIRECTED PROGRAMMING AND NEURAL  
NETWORKS****Y. Kobayashi and H. Nonaka**

1. Introduction .....	421
2. Method.....	422
2.1. Problem and method description .....	422
2.2. Knowledge - based method for lower - level problems.....	424
2.3. Knowledge - based scheduling method for upper- level problems .....	431
2.4. Neural networks for upper - level problems.....	432
3. Application Examples.....	439
3.1. Scheduling systems.....	439
3.2. Problem.....	439
3.3. Results .....	439
4. Conclusions .....	444
References .....	445

**PART 4****SYSTEM DIAGNOSTICS****CHAPTER 15****KNOWLEDGE - BASED FAULT DIAGNOSIS OF TECHNOLOGICAL  
SYSTEMS****H. Verbruggen, S. Tzafestas and E. Zanni**

1. Introduction .....	449
2. Knowledge Representation and Acquisition for Fault Diagnosis .....	451
2.1. Knowledge representation .....	451

2.2. Knowledge acquisition .....	454
3. First -and Second - Generation Diagnostic Expert Systems.....	456
3.1. General issues .....	456
3.2. First - generation expert systems .....	456
3.3. Deep reasoning .....	457
3.4. Qualitative reasoning .....	458
3.5. Second - generation expert systems.....	462
4. A General Look at the FD Methodologies and Second - Generation ES	
Architectures.....	462
4.1. General issues .....	462
4.2. Diagnostic modelling.....	463
4.3 Second - generation FD expert system architectures.....	464
5. A Survey of Digital Systems Diagnostic Tools.....	467
5.1. The D - algorithm .....	467
5.2. Davis' diagnostic methodology .....	468
5.3. Integrated diagnostic model (IDM) .....	470
5.4. The diagnostic assistance reference tool (DART).....	472
5.5 The intelligent diagnostic tool (IDT).....	474
5.6. The Lockheed expert system (LES) .....	476
5.7. Other systems .....	476
6. A General Methodology for the Development of FD Tools in the Digital	
Circuits Domain.....	477
6.1. Description of the structure .....	478
6.2. Description of the behaviour .....	479
6.3. The diagnostic mechanism .....	480
6.4. The constraint suspension technique .....	482
6.5. Advantages of the deviation detection and constraint	
suspension technique .....	485
7. A General Methodology for the Development of FD Tools in the	
Process Engineering Domain.....	486
8. Implementation of a Digital Circuits Diagnostic Expert System (DICIDEX) 489	
8.1. Introduction .....	489
8.2. Digidex description.....	490
8.3. Examples of system - user dialogues.....	496