
INTELLIGENT BUILDING SYSTEMS

The Kluwer International Series on ASIAN STUDIES IN COMPUTER AND INFORMATION SCIENCE

Series Editor

Kai-Yuan Cai

*Beijing University of Aeronautics
Beijing, CHINA*

Editorial Advisory Board

Han-Fu Chen, Institute of System Science, Chinese Academy of Sciences

Jun-Liang Chen, Beijing University of Post and Telecommunication

Lin Huang, Peking University

Wei Li, Beijing University of Aeronautics and Astronautics

Hui-Min Lin, Institute of Software Technology, Chinese Academy of Sciences

Zhi-Yong Liu, Institute of Computing Technology, Chinese Academy of Sciences

Ru-Qian Lu, Institute of Mathematics, Chinese Academy of Sciences

Shi-Tuan Shen, Beijing University of Aeronautics and Astronautics

Qing-Yun Shi, Peking University

You-Xian Sun, Zhejiang University

Lian-Hua Xiao, National Natural Science Foundation of China

Xiao-Hu You, Southeast University

Bo Zhang, Tsinghua University

Da-Zhong Zheng, Tsinghua University

Bing-Kun Zhou, Tsinghua University

Xing-Ming Zhou, Changsha University of Technology

Also in the Series:

**PERFORMANCE EVALUATION, PREDICTION AND
VISUALIZATION OF PARALLEL SYSTEMS** by *Xingfu Wu*;
ISBN: 0-7923-8462-8

**SOFTWARE DEFECT AND OPERATIONAL PROFILE
MODELING** by *Kai-Yuan Cai*; ISBN: 0-7923-8259-5

**FUZZY LOGIC IN DATA MODELING: Semantics, Constraints,
and Database Design** by *Guoqing Chen*; ISBN: 0-7923-8253-6

**ROBUST MODEL-BASED FAULT DIAGNOSIS FOR DYNAMIC
SYSTEMS** by *Jie Chen and Ron J. Patton*; ISBN: 0-7923-8411-3

INTELLIGENT BUILDING SYSTEMS

by

Albert Ting-pat So

City University of Hong Kong

*Johnson Controls Intelligent Building Research Centre
City University of Hong Kong*

Wai Lok Chan

Hong Kong Polytechnic University

*Johnson Controls Intelligent Building Research Centre
City University of Hong Kong*



SPRINGER SCIENCE+BUSINESS MEDIA, LLC

ISBN 978-1-4613-7280-6 ISBN 978-1-4615-5019-8 (eBook)
DOI 10.1007/978-1-4615-5019-8

Library of Congress Cataloging-in-Publication Data

A C.I.P. Catalogue record for this book is available
from the Library of Congress.

Copyright © 1999 by Springer Science+Business Media New York
Originally published by Kluwer Academic Publishers in 1999
Softcover reprint of the hardcover 1st edition 1999

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, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher, Springer Science+Business Media, LLC.

Printed on acid-free paper.

This book is dedicated by Albert So
to his wife Sau-ling
and two daughters Shirley and Sylvia

Contents

Preface		xi
Acknowledgments		xv
1	INTRODUCTION TO INTELLIGENT BUILDING	1
1.1.	Introduction	1
1.2.	The Definition of IB in U.S.A.	1
1.3.	The Definition of IB in Europe	2
1.4.	Existing Definitions of IB in Asia	3
1.5.	A New Definition of IB for Asia	4
1.6.	Cost Analysis of IB	6
1.7.	Conclusion	6
1.8.	References	6
2	HEATING, VENTILATION AND AIR-CONDITIONING	7
2.1.	Introduction	7
2.2.	Human Comfort	7
2.3.	Comfort Air-conditioning	10
2.4.	Classification of Air-conditioning Sub-systems	11
2.5.	Air-conditioning Systems	13
2.6.	References	14
3	ELECTRICAL INSTALLATION AND ILLUMINATION	15
3.1.	Introduction	15
3.2.	Terminologies in Electrical Power Engineering	15
3.3.	Electric Power Transmission to Buildings	17
3.4.	Electric Power Systems in Buildings	18
3.5.	Electric Power Quality in Buildings	20
3.6.	Lighting Systems in Buildings	23
3.7.	References	26
4	VERTICAL TRANSPORTATION SYSTEMS	27
4.1.	Introduction	27

4.2.	Structure of a Lift	27
4.3.	Lift Drives	30
4.4.	Lift Traffic Analysis	31
4.5.	Supervisory Control	33
4.6.	Remote Monitoring	34
4.7.	References	34
5	FIRE PROTECTION SYSTEMS	35
5.1.	Introduction	35
5.2.	Types of Fire Services Installations	35
5.3.	Automatic Fire Alarm and Detection	35
5.4.	Sprinklers	36
5.5.	Hose Reels and Hydrants	37
5.6.	Foam Systems	37
5.7.	Microprocessor Based Fire Alarm Systems	38
5.8.	References	38
6	SECURITY AND SAFETY SYSTEMS	39
6.1.	Introduction	39
6.2.	Designing a Security System	39
6.3.	Intrusion Sensors and Space Sensors	39
6.4.	Closed Circuit Television Systems	40
6.5.	Central Alarm Systems	40
6.6.	References	40
7	BUILDING AUTOMATION AND ENERGY MANAGEMENT	41
7.1.	Introduction	41
7.2.	History of Development of BAS	41
7.3.	A Typical BAS in the 90's	42
7.4.	Criteria of Choosing the Right BAS	46
7.5.	The Open System Architecture	46
7.6.	References	46
8	BUILDING ELECTRONICS	47
8.1.	Introduction	47
8.2.	Microprocessor Based Control	47
8.3.	Programmable Logic Controllers	49
8.4.	Communication Principles	49
8.5.	Telephone System	52
8.6.	Communal Aerial Broadcasting	54
8.7.	Satellite Communication	55
8.8.	Fiber Optic System	57
8.9.	Computer Network Technology	59
8.10.	References	62

9	A REVIEW ON USEFUL MATHEMATICAL TOOLS	63
9.1.	Introduction	63
9.2.	Vector and Matrix Algebra	63
9.3.	Linear Equation Systems and Vector Spaces	65
9.4.	Eigenvalues and Eigenvectors	66
9.5.	Linear Transformation	67
9.6.	Multivariate Calculus	67
9.7.	Optimisation	67
9.8.	Probability and Statistics	68
9.9.	Curve Fitting	70
9.10.	References	70
10	A REVIEW ON ARTIFICIAL INTELLIGENCE METHODS	71
10.1.	Introduction	71
10.2.	Expert System	71
10.3.	Computer Algebra	73
10.4.	Fuzzy Systems	75
10.5.	Neural Network	79
10.6.	Genetic Algorithm	82
10.7.	Simulated Annealing	83
10.8.	References	84
11	DIGITAL SIGNAL PROCESSING AND COMPUTER VISION	85
11.1.	Introduction	85
11.2.	Generation of Digital Signal	85
11.3.	Discrete Fourier Transform	86
11.4.	Digital Filtering	87
11.5.	Spectral Analysis	89
11.6.	Generation of Digital Image	89
11.7.	Basic Image Processing	90
11.8.	Computer Vision Principles	91
11.9.	References	92
12	APPLICATIONS IN HVAC SYSTEMS	93
12.1.	Introduction	93
12.2.	Knowledge-based Design	93
12.3.	Expert System Based Maintenance	95
12.4.	System Identification Based Control	96
12.5.	Computer Vision Based Control	101
12.6.	Neural Network Based Control	106
12.7.	Static Fuzzy Logic Based Control	111
12.8.	Self-learning Fuzzy Logic Based Control	116
12.9.	References	122

13	APPLICATIONS IN ELECTRICAL SYSTEMS	123
13.1.	Introduction	123
13.2.	Computer Vision Based Metering	123
13.3.	Fuzzy Logic Based Power Harmonics Patterns Recognition	125
13.4.	Artificial Neural Network Based Harmonics Evaluation	130
13.5.	Computer Vision Based Lighting Control	134
13.6.	Outdoor Lighting Design by Computer Algebra	137
13.7.	References	142
14	APPLICATIONS IN FIRE SERVICES	143
14.1.	Introduction	143
14.2.	Drawbacks of Conventional Systems	143
14.3.	Core Computer Vision System for Security and Fire Detection	143
14.4.	Extended Computer Vision System	145
14.5.	Degree of Chaos	146
14.6.	References	146
15	APPLICATIONS IN VERTICAL TRANSPORTATION	147
15.1.	Introduction	147
15.2.	Simulation and Modelling	147
15.3.	Digital Monitoring	148
15.4.	Expert System Based Supervisory Control	149
15.5.	Comprehensive Dynamic Zoning Algorithms	150
15.6.	Fuzzy Logic Based Supervisory Control	157
15.7.	Computer Vision Based Supervisory Control	158
15.8.	Artificial Neural Network Based Supervisory Control	158
15.9.	References	161
16	APPLICATIONS IN ENERGY MANAGEMENT AND DESIGN	163
16.1.	Introduction	163
16.2.	Impact of AI Technology in the HVAC Industry	163
16.3.	ANN Based Energy Management	164
16.4.	Multiple Cooperating Knowledge Sources for Designing Energy Systems	165
16.5.	References	166
17	THE FUTURE OF INTELLIGENT BUILDING SYSTEMS	167
17.1.	Introduction	167
17.2.	Data Management Centre	167
17.3.	Distributed Intelligence	170
17.4.	Pneumatic vs Electronic	170
17.5.	Common Protocols	171
17.6.	Domestic Applications	172
17.7.	Multi-media Approaches	172
17.8.	References	172

Preface

This book is about the integration of artificial intelligence (AI) with building services systems. It describes what has been existing in a modern intelligent building and what is being developed by researchers to enhance human comfort, working efficiency and energy performance for buildings in the 21st century. It is relevant to practitioners and researchers in the areas of architectural science and engineering, electrical and mechanical services in buildings, and intelligent buildings. The book was intentionally written as a text or reference book for final year undergraduate or first year postgraduate students in architecture, building services engineering, electrical engineering, mechanical engineering and electronic engineering and other disciplines related to the building and construction industry.

It is generally accepted that we, citizens, normally spend 80% of our lives in buildings, say 8 hours in office, 8 hours on the bed and 4 hours in restaurants or at home daily. Even when we are outside a building, we may perhaps be travelling from one building to another. This viewpoint justifies an intensive research on the development of technologies to continuously improve our built environment and hence, the concept of "intelligent building" becomes very popular in nowadays. Building systems, or electrical and mechanical services systems in conventional terms, such as heating, ventilation and air-conditioning, electrical services, lighting and vertical transportation etc., are vital to the realisation of this concept. During recent decades, we have seen rapid progress in the advancement of both hardware and software aspects of building systems which have grown from a "dummy" mode to a "smart" or "intelligent" mode. Techniques in advanced electronics and artificial intelligence have been employed in making such transition come true. The goal of preparing this book is to present a clear picture to our readers existing concepts and technologies involved in the services systems of modern intelligent buildings. Results from recent research works are introduced to initiate our insight into future development in relevant areas.

With this book, we are able to learn how to improve the performance of building systems by techniques in artificial intelligence. At the same time, we are able to verify that all these AI techniques are not just developed to fulfil academic interests. They actually have real applications and these applications will give feedback to refine the AI algorithms designed before. Such a closed-loop process can guarantee a perfect intelligent building in the future.

The book can roughly be divided into three parts.

Part I, consisting of seven chapters, contains a brief summary on standard building systems where the basic structure and operating principles are discussed.

Part II, consisting of four chapters, gives an introduction to the background knowledge necessary for understanding different aspects of AI.

Part III, consisting of the remaining six chapters, is a general review on the application of AI techniques on different building systems to enhance their performance.

Part I is described through chapter 1, 2, 3, 4, 5, 6 and 7 respectively.

Chapter 1: The definition of intelligent buildings is studied. There is, at present, no one globally accepted definition for intelligent buildings. The definitions in United States, Europe, Singapore, Japan and China are reviewed. A new definition which can assist building design has been proposed by the authors.

Chapter 2: Heating, ventilation and air-conditioning (HVAC) systems consume up to half of the total energy consumption of a modern commercial building. Criteria of thermal comfort are introduced as a basis to appreciate HVAC design. Different HVAC systems are briefly discussed.

Chapter 3: Electrical installations serve to convey energy to every part of the building. Terminologies and basic components are highlighted. The growing concern of electric power quality, in particular harmonics pollution, is addressed. Finally, fundamentals in illumination engineering are included.

Chapter 4: Vertical transportation systems provide the means of free movement by occupants around a building. The structure of two types of common elevators and the operating principles of lift drives are discussed. Based on lift traffic analysis, a good elevator system design can be achieved. Supervisory control systems help to ensure desirable operation while remote monitoring enhances the safety and maintenance aspects.

Chapter 5: The most serious hazard of a building, in many countries, is fire outbreak. Different fire fighting systems are highlighted in this chapter.

Chapter 6: We all desire a safe environment for working and residence. Building security systems provide us the means to stay in a building safely, against crime risk.

Chapter 7: The heart of an intelligent building is a comprehensive building automation system (BAS). The history of development, hardware structure and

software features of a typical BAS is included. The concept of open architecture is introduced.

Part II is described through chapters 8, 9, 10 and 11 respectively.

Chapter 8: Thanks to the advancement of electronics technology, implementation of sophisticated controllers and the BAS has been successful. This chapter gives a general review on different electronics systems in a modern commercial building. Communication electronics is amongst the most important issue.

Chapter 9: Besides electronics, the underlying theories of AI techniques very much rely on mathematics. A quick review on the mathematical tools used in this book is given in this chapter, including linear algebra, optimisation, probability and curve fitting.

Chapter 10: The integration between AI and building systems is the main theme of this book. In this chapter, popular AI techniques are introduced, which have applications in Part III of the book. Topics include expert systems, computer algebra, fuzzy systems, neural networks and genetic algorithms.

Chapter 11: Building system controllers must first of all monitor the current status of environmental parameters and then decide on the appropriate control actions. Signals measured must be suitably processed into digital form and fed to the control engine inside the controller. This chapter includes techniques in digital signal processing and slightly touches on computer vision which can be considered as the processing of two-dimensional signals.

Part III is described through chapters 12, 13, 14, 15, 16 and 17 respectively.

Chapter 12: Research works on the applications of AI techniques on HVAC systems are introduced. The use of expert systems, system identification, fuzzy control, neural network based control and computer vision based control are described in reasonably details.

Chapter 13: Research works on the application of AI techniques on electrical systems are introduced. Fuzzy logic based and artificial neural network based power harmonics pattern recognitions are quite interesting. Outdoor lighting design with computer algebra is also a very new application.

Chapter 14: A computer vision based fire detection system is discussed in this chapter.

Chapter 15: Actually, the number of AI applications in vertical transportation systems is highest among all other building systems. Quite a substantial part of the description in this chapter can really be found in the market. We shall talk

about simulation and modelling, expert system based control, fuzzy logic based control, artificial neural network based control and computer vision based control. Dynamic zoning is an extension of two practical systems currently available in the market.

Chapter 16: The impact of AI technology in the HVAC industry is first discussed. Expert system applications in energy management form the major part of this chapter.

Chapter 17: As we have gone through existing systems and research results, it is time we thought about our future, in particular, during the turn of the millennium. The views included in this chapter are quite conservative and we have confidence that all these dreams will come true within the next decade. Readers of this book are highly encouraged to leap forward by a large step and think about innovative features of intelligent building systems, say thirty to forty years in the future.

Most of the contents in Part III of this book have been based on recent research achievements of the authors. For further correspondence from readers who are interested in one or more sections of this book, please gain access to our research centre Homepage "<http://www.jcibrc.org.hk>", or send an e-mail to "albert.tp.so@ieee.org".

ALBERT T. SO

Acknowledgements

The authors would like to acknowledge the support and assistance of Wai L. Tse, Thomas K. Li, Kwok C. Wong, Rosa S. Tchao and Ka Y. Sin for invaluable advice, and the preparation of computer programs, tables and drawings. The authors have been indebted to Prof. Kai Y. Cai and Prof. Kumar David since the initial stage for their strong encouragement. Wai L. Chan would like to thank the spiritual support of Miss Gao.

SERIES EDITOR'S ACKNOWLEDGMENTS

I am pleased to acknowledge the assistance to the editorial work by Beijing University of Aeronautics and Astronautics and the National Natural Science Foundation of China

Kai-Yuan Cai
Series Editor
Department of Automatic Control
Beijing University of Aeronautics and Astronautics
Beijing 100083
China