Studies in Computational Intelligence 404

For further volumes:
http://www.springer.com/series/7092

Ahmad Taher Azar (Ed.)

Modeling and Control of Dialysis Systems

Volume 1: Modeling Techniques of Hemodialysis Systems

Springer

Editor
Ahmad Taher Azar, PhD, IEEE Member
Assistant Professor, Computer and Software Engineering Department,
Faculty of Engineering,
Misr University for Science & Technology (MUST),
6th of October City, Egypt.
Editor in Chief of International Journal Of System Dynamics Applications (IJSDA),
IGI-Global, USA.

Additional material to this book can be downloaded from http://extra.springer.com

ISSN 1860-949X e-ISSN 1860-9503
ISBN 978-3-642-27457-2 e-ISBN 978-3-642-27458-9
DOI 10.1007/978-3-642-27458-9
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2011945321

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Dedication

I dedicate this book to my wife, her endless prayers through days and nights keep lighting me the way and without her patience, understanding and support the completion of this work would not have been possible. To my dearest, beautiful and extraordinary daughters Hla and Nadine to whose love will always be an inspiration for me. I wish to dedicate this book also, to my mother. She taught me to persevere and prepared me to face challenges with faith and humility. She is a constant source of inspiration to my life. I always feel her presence used to urge me to strive to achieve my goals in life. Also, to my sisters for their endless love, patience, trust and sacrifices for me.

Preface

The primary purpose of the book is to facilitate education in the increasingly important areas of dialysis. It is written as a textbook for a course at the graduate or upper-division undergraduate level for biomedical engineering students. The biomedical engineering is the inter marriage of engineering and medicine. The need to effectively utilize high technology equipment and systems in the dialysis field necessitates the expertise of clinical engineers, hospital physicians and computer scientists. Hardly any patient today would pass through a hospital or even a family physician's chamber without the use of this technology.

Although there is enough material in the text for nephrologists, nurses, technicians and other members of the health care team resolve the myriad of problems confronting the patients undergoing dialysis. The text is also suitable for self study and for short, intensive courses of continuing education. The authors include a senior consultant nephrologist with considerable expertise in all aspects of dialysis. Advanced topics and future challenges are addressed as well, with the researchers in the field in mind. The introductory material, application oriented techniques, and case studies should be particularly useful to practicing professionals.

While several books are available today that address the principles of dialysis, none, unfortunately, provides the practicing knowledge engineer, system analyst, and biomedical researchers with specific, practical information about various modeling and control techniques in the field of dialysis and their applications. The book discusses novel ideas and provides a new insight into the studied topics. The book on this subject will constitute an important contribution in the field of hemodialysis and peritoneal dialysis.

The book is unique for its diversity in contents, clarity and precision of presentation and the overall completeness of its chapters. Each chapter in the book openes with a chapter outline, chapter objectives, key terms list and chapter abstract. Each chapter ends with a conclusion and bibliographic references related to the text. The book is basically broken into two volumes with five parts. The first volume includes the first part of the book from chapters 1–14 which covers overview of dialysis treatment and urea kinetic modeling techniques. There are three treatment modalities

available for patients with chronic renal failure: hemodialysis (HD), peritoneal dialysis (PD), and renal transplantation (RT). Although these treatment modalities have proved to be life sustaining, patients with end-stage renal disease (ESRD) continues to grow in the worldwide. The incident population of patients with ESRD is increasing at approximately 6% each year. Kidney transplantation is considered the treatment of choice for many people with severe chronic kidney disease because quality of life and survival are often better than in people who use dialysis. Despite assiduous efforts to utilize renal transplantation as a viable option for potential recipients with ESRD, the donor organ shortage has been one of the major barriers to kidney transplantation. Patients who are not candidates for kidney transplantation or who must wait for a kidney can usually be treated with either hemodialysis or peritoneal dialysis. Dialysis prescription must ensure that an adequate amount of dialysis is delivered to the patient. Numerous studies have shown a correlation between the delivered dose of hemodialysis and patient morbidity and mortality. Therefore, the delivered dose should be measured and monitored routinely to ensure that the patient receives an adequate amount of dialysis. Urea Kinetic Modeling (UKM) is beneficial because it assists clinicians in individualizing dialysis prescriptions and provides the hemodialysis care team with guidance about which specific parameters of the prescription to modify to achieve the target hemodialysis dose. The presentation of these chapters requires only a basic knowledge of linear algebra, differential equations and probability theory.

The second volume of the book includes the remaining parts (from part 2 to part 5). The second part of the book from chapters 15–19 describes online dialysis monitoring devices and continuous therapy. In the past few years, several devices have been developed in the field of dialysis. These devices obviate the need for blood sampling, minimize random measurement errors, and allow a whole range of parameters to be calculated which are likely to be of future clinical value. These new devices also may be coupled on-line to a central database so that measured and calculated values can be recorded without manual intervention, allowing almost instant information of clinical value to the patient.

The third part of the book from Chapters 20–25 covers biofeedback Systems and soft computing Techniques of dialysis. Biofeedback represents the first step towards a ‘physiological’ HD system incorporating adaptive and logic controls in order to achieve pre-set treatment targets and to ensure delivery of the prescribed dialysis dose. Soft computing approaches in decision making have become increasingly popular in many disciplines. Soft computing concerns the use of theories of fuzzy logic, neural networks, and evolutionary computing to solve real-world problems that cannot be

satisfactorily solved using conventional crisp computing techniques. A novel applications of soft computing techniques are discussed in this part of the book. While sufficient theory of each technique is presented, it is offered in a simplified manner for the benefit of the students.

The fourth part of the book from Chapters 26–30 covers the overview of peritoneal dialysis and its modeling techniques.

Finally, the fifth part of the book has two chapters to cove the future challenges and general guidelines of dialysis.

It is hoped that the book will be a very good compendium for almost all readers — from students of undergraduate to postgraduate level and also for researchers, professionals, etc. — who wish to enrich their knowledge on dialysis systems' principles and applications with a single book in the best manner.

Solved Examples, Applications, and Implementation Case Studies

A vast array of illustrative examples, implementation case studies for a variety of applications, end-of-chapter questions and problems are used throughout the text. There are over 1000 questions in this textbook. The basic goals of these case studies, examples and questions are as follows:

- To help illustrate the theory.
- To encourage good problem-solving skills.
- To show how to apply the techniques.
- To help illustrate design procedures in a concrete way.
- To show what practical issues are encountered in the development and implementation of dialysis systems.

To the Student

The best way to learn new material is by reading, thinking, and doing. This text is designed to help you along the way by providing an overview and objectives for each section, numerous worked- out examples, exercises and self-test questions. Read each section of the text carefully and think about what you have read. Sometimes you may need to read the section more than once. Work through each example problem step by step before you try the related problem that goes with the example. After the end of each chapter, answer the essay questions and multiple choice questions. The abundance of these questions is very useful for you to check your progress and understanding as they require more systematic and in-depth thinking. If you are able to solve the chapter questions for a given objective, you have mastered that objective.

For Instructors

A. Instructor Solutions Manual

Fully worked-out solutions to end-of chapter questions and problems. So you can check your work.

B. Possible Course Structures

The material in this textbook has been designed for a one-semester, two-semester, or three-quarter sequence depending on the needs and interests of the instructor. The material in the book is suitable for a number of courses at the undergraduate and graduate levels. Some possibilities are given below.

- Dialysis principles (senior undergraduate or introductory graduate-level course): Chapters 1, 2, 3, 4, 5, 7, 9, 26, 27, 30, 31 and 32.
- Modeling techniques of dialysis (senior undergraduate or graduate-level course): Chapters 6, 8, 10, 11, 12, 13, 14, 19, 25, 28 and 29.
- Online dialysis monitoring and continuous therapy (senior undergraduate or introductory graduate-level course): Chapters 15, 16, 17, 18, 19, 25.
- Biofeedback Systems and Soft computing applications in dialysis (senior undergraduate or graduate-level course): Chapters 20, 21, 22, 23, 24, and 25.
- Principles of peritoneal dialysis and its modeling techniques (senior undergraduate or graduate-level course): Chapters 26, 27, 28, 29, and 30.

Feedback on the Book

We are deeply indebted to the many instructors and students who have offered positive feedback and suggestions for improvement. We are delighted whenever we receive email from instructors and students who use the book, even when they are pointing out an error we failed to catch in the review process. We are also open to your suggestions on how to improve the content, the pedagogy, and the presentation in this text by emailing me at ahmad_t_azar@yahoo.com. We are privileged to have the opportunity to impact the educational experience of the many thousands of future engineers who will turn the pages of this text.

Acknowledgements

My sincere thanks to all contributing authors of this book not only because of their expertise in the science of medicine, but because they are physicians who are able to translate and apply their scientific knowledge in a practical way to allow for a systematic and evidence based plan of therapy and treatment in the best interests of patients.

Special thanks go to our publisher, Springer-Verlag Berlin Heidelberg and data processing team Prabu G., and Shenbagavadivu D. for their valuable review during the publication process. Special thanks for the tireless work of the series editor of Studies in Computational Intelligence, Dr. Thomas Ditzinger.

Ahmad Taher Azar, PhD, IEEE Member
Assistant Professor, Computer and Software Engineering Department,
Faculty of Engineering, Misr University for Science & Technology (MUST),
6th of October City, Egypt.
Editor in Chief of International Journal Of System
Dynamics Applications (IJSDA),
IGI-Global, USA.

About the Editor

Dr. Ahmad Azar has received the M.Sc. degree (2006) in System Dynamics and Ph.D degree (2009) in Adaptive Neuro-Fuzzy Systems from Faculty of Engineering, Cairo University (Egypt). He is currently Assistant Professor, Computer and Software Engineering Department, Faculty of Engineering, Misr University for Science & Technology (MUST), Egypt. Dr. Ahmad Azar has worked in the areas of System Dynamics, Intelligent Control, soft computing and Modelling in Biomedicine and is the author of more than 40 papers in these subjects. He is an editor of four Books in the field of Fuzzy logic systems and biomedical Engineering. Dr. Ahmad Azar is closely associated with several international journals as a reviewer. He serves as international programme committee member in many international and peer-reviewed conferences. He currently serves as the Editor of a lot of international journals. His biography was selected to appear in the 27th and 29th Editions of Who's Who in the World, Marquis Who's Who, USA, 2010 and 2012, respectively. Dr Ahmad Azar is currently the Vice chair of IEEE Computational Intelligence Society (CIS) Egypt Chapter and Vice President Of Egypt System Dynamics Chapter. He is an Academic Member of IEEE Systems, Man, and Cybernetics Society Technical Committee on Computational Collective Intelligence and also a member in KES Focus Group on Agent and Multi-agent Systems. His reserach interests include: Control System Analysis, Systems Engineering, System Dynamics, Medical Robotics, Process Control, Neural network, Fuzzy logic controllers, Neuro-Fuzzy systems, System thinking, Mathematical Modeling and Computer Simulation, Statistical Analysis, Decision Making Analysis, Research Methodology, Biofeedback systems, Monitoring and Controlling of Hemodialysis System.

Contents

Contributing Authors

Ahmad Taher Azar
Assistant Professor, Computer and Software Engineering Department, Faculty of Engineering, Misr University for Science & Technology (MUST), 6th of October City, Egypt.
Editor in Chief of International Journal of System Dynamics Applications (IJSDA), IGI-Global, USA.
e-mail: ahmad_t_azar@ieee.org

Alexandre Granger Vallée
Lapeyronie University Hospital - CHRU Montpellier, France
e-mail: alexandre.granger@videotron.ca

Alicja E. Grzegorzewska
Poznań University of Medical Sciences, Poland
e-mail: alicja_grzegorzewska@yahoo.com

Alfonso Lara
Biomedical Engineering Group, University of Sevilla, ESI, Seville, Spain/ Service of Nephrology, University Hospital Virgen Macarena, Seville, Spain
e-mail: alararnet@hotmail.com

Alfonso Palma: MD, PhD
Senior Researcher at the Biomedical Engineering Group of the University of Seville, Spain.
e-mail: apalmaa@senefro.org

Andrea Cavalli
"A. Manzoni" Hospital Departement of Nephrology, Dialysis and Renal Transplant, Italy
e-mail: a.cavalli@ospedale.lecco.it

Antonio Santoro
Nephrology Dialysis Hypertension Unit;
Policlinico S.Orsola-Malpighi, Italy
e-mail: antonio.santoro@aosp.bo.it

Aron S. Bode
Maastricht University Medical Center, The Netherlands
e-mail: dr.as.bode@gmail.com

Ashita Jiwat Tolwani
University of Alabama at Birmingham, USA
e-mail: atolwani@uab.edu

Bernard Canaud MD, PhD
Professor of Nephrology Montpellier II University School of Medicine;
Head, Nephrology, Dialysis and Intensive Care Unit, Lapeyronie Hospital,
Montpellier, France
e-mail: b-canaud@chu-montpellier.fr

Bertrand L. Jaber
Associate Professor of Medicine St. Elizabeth's Medical Center,
Department of Medicine, USA
e-mail: bertrand.jaber@steward.org

Casper F.M. Franssen
University Medical Center Groningen Department of Internal Medicine,
Division of Nephrology, The Netherlands
e-mail: c.f.m.franssen@int.umcg.nl

Celestina Manzoni
"A. Manzoni" Hospital Departement of Nephrology, Dialysis and
Renal Transplant, Italy
e-mail: c.manzoni@ospedale.lecco.it

Claudio Ronco
San Bortolo Hospital, Italy
e-mail: cronco@goldnet.it

Daniel Schneditz
Medical University of Graz, Institute of Physiology, Austria
e-mail: daniel.schneditz@medunigraz.at

Elena Mancini
Nephrology Dialysis Hypertension Unit; Policlinico S. Orsola-Malpighi, Italy
e-mail: elena.mancini@aosp.bo.it

Elmer Fernandez
CONICET - School of Engineering, Universidad Católica de Córdoba, Argentina
e-mail: elmerfer@gmail.com

David Naranjo
Network Center of Biomedical Research in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN)/
Biomedical Engineering Group,
University of Sevilla, ESI, Seville, Spain
e-mail: davidazuaga@gmail.com

Declan G. de Freitas
Consultant Nephrologist, Assistant Adjunct Professor, UK
e-mail: declan.defreitas@cmft.nhs.uk

Fredrik Uhlin
Department of Nephrology UHL, County Council of Östergötland and Department of Medical Health Sciences, Faculty of Health Sciences, Linköping University, Linköping, Sweden
e-mail: fredrik.uhlin@lio.se

Francesco Locatelli
"A. Manzoni" Hospital Departement of Nephrology, Dialysis and Renal Transplant, Italy
e-mail: f.locatelli@ospedale.lecco.it

Geoff McDonnell
Centre for Health Informatics, University of News South Wales, Coogee Campus, Sydney
e-mail: gmcdonne@bigpond.net.au

Giuseppe Pontoriero
"A. Manzoni" Hospital Departement of Nephrology, Dialysis and Renal Transplant, Italy
e-mail: g.pontoriero@ospedale.lecco.it

Hélène Leray Moragues
Lapeyronie University Hospital - CHRU Montpellier, France
e-mail: h-leray_moragues@chu-montpellier.fr

Ivo Fridolin
Department of Biomedical Engineering, Technomedicum,
Tallinn University of Technology, Estonia
e-mail: ivo@cb.ttu.ee

Jan H.M. Tordoir
Maastricht University Medical Center, The Netherlands
e-mail: j.tordoir@mumc.nl

Javier Reina-Tosina
Network Center of Biomedical Research in Bioengineering,
Biomaterials and Nanomedicine (CIBER-BBN), Spain
e-mail: jreina@us.es

J. Chris White
ViaSim Solutions, USA
e-mail: jcwhite@viasimsolutions.com

J. Sergio Oliva
Biomedical Engineering Group, University of Sevilla, ESI, Seville, Spain
e-mail: joliva@us.es

John H. Crabtree
Department of Surgery, Southern California Permanente Medical Group,
Kaiser Permanente Downey Medical Center, Downey, California;
Visiting Clinical Faculty, Division of Nephrology and Hypertension,
Harbor- University of California Los Angeles Medical Center, Torrance,
California, USA
e-mail: johncrabtree@sbcglobal.net

Jorge Cerda
Albany Medical College, USA
e-mail: cerdaj@mail.amc.edu

José A. Milán
Biomedical Engineering Group, University of Sevilla, ESI, Seville, Spain /
Network Center of Biomedical Research in Bioengineering,
Biomaterials and Nanomedicine (CIBER-BBN)/ Service of Nephrology,
University Hospital Virgen Macarena, Seville, Spain
e-mail: josea.milan.sspa@juntadeandalucia.es

Judith J. Dasselaar
University Medical Center Groningen Department of Internal Medicine,
Division of Nephrology, The Netherlands
e-mail: judithdasselaar@home.nl

Karen Chia-Ying To
McMaster University, Canada
e-mail: karen.to@medportal.ca

Kenneth Scott Brimble
McMaster University, Canada
e-mail: brimbles@mcmaster.ca

Luciano Alberto Pedrini
Department of Nephrology and Dialysis. Bolognini Hospital – Seriate, Italy
e-mail: luciano.pedrini@fmc.ag.com

Laura M. Roa
Biomedical Engineering Group, University of Sevilla, ESI, Seville, Spain / Network Center of Biomedical Research in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Spain
e-mail: lroa@us.es

Laura M. Rosales
Renal Research Institute, USA
e-mail: lrosales@rriny.com

Laure Patrier
Lapeyronie University Hospital - CHRU Montpellier, France
e-mail: l.patrier@chu-montpellier.fr

Leila Chenine Koualef
Lapeyronie University Hospital - CHRU Montpellier, France
e-mail: l-chenine@chu-montpellier.fr

Leonard M. Ebah
Specialist Registrar in Renal Medicine, UK
e-mail: leonard.ebah@cmft.nhs.uk

Manuel Prado Velasco
M2TB, University of Seville, Spain
e-mail: mpradovelasco@ieee.org

Marion Morena
Lapeyronie University Hospital - CHRU Montpellier & Institut de Recherche et Formation en Dialyse, France
e-mail: marion.morena@gmail.com

Masatomo Yashiro
Division of Nephrology, Kyoto City Hospital, Japan
e-mail: yashiro@pearl.ocn.ne.jp

Michael Francis Flessner
National Institutes of Health USA
e-mail: flessnermf@niddk.nih.gov

Maurizio Nordio
Nephrology and Dialysis Unit - ULSS 15 “Alta Padovana”, Italy
e-mail: maurizio.nordio@gmail.com

Miguel Ángel Estudillo
Network Center of Biomedical Research in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN)/ Biomedical Engineering Group, University of Sevilla, ESI, Seville, Spain
e-mail: m.estudillo@gmail.com

Monica Graciela Balzarini
CONICET - Biometrics Department, School of Agronomy, Universidad Nacional de Cordoba, Argentina
e-mail: mbalzari@gmail.com

Nathan W. Levin
Renal Research Institite, USA
e-mail: nlevin@rriny.com

Nestor Velasco
Crosshouse Hospital, Kilmarnock, United Kingdom
e-mail: Nestor.Velasco@aaaht.scot.nhs.uk

Orfeas Liangos
Adjunct Assistant Professor of Medicine Tufts University School of Medicine Klinikum Coburg Coburg, Germany
e-mail: liangos_o@hotmail.com

Philip Alan McFarlane
St. Michael's Hopsital, University of Toronto, Canada
e-mail: phil.mcfarlane@utoronto.ca

Pranay Kathuria
University of Oklahoma School of Medicine, USA
e-mail: pranay-kathuria@ouhsc.edu

Rajnish Mehrotra
Associate Chief, Division of Nephrology and Hypertension, Department of Medicine, Harbor-UCLA Medical Center, Torrance, CA, and Professor of Medicine, David Geffen School of Medicine at UCLA, Los Angeles, CA, USA
e-mail: rmehrotra@labiomed.org

Rodolfo Valtuille
Fresenius Medical Care Argentina, Argentina
e-mail: rvaltuille@gmail.com

Salvatore Di Filippo
"A. Manzoni" Hospital Departement of Nephrology, Dialysis and Renal Transplant, Italy
e-mail: s.difilippo@ospedale.lecco.it

Shamik Shah
Apollo Hospitals Ahmedabad, India
e-mail: shamik.shah@yahoo.com

Silvio Giove
Department of Economics, University of Venice, Italy
e-mail: sgiove@unive.it

Suhail Ahmad MD
Associate Professor of Medicine University of Washington; Medical Director, Scribner Kidney Center, Seattle, Washington
e-mail: sahmad@u.washington.edu

Thomas M. Kitzler
McGill University-Divison of Nephrology Lyman Duff Medical Building Montreal, Quebec, Canada
e-mail: thomas.kitzler@mcgill.ca

Wayne G. Carlson
Minntech Corp. USA
e-mail: wcarlson@minntech.com