Thomas M. Deserno

Editor

BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING

Biomedical Image Processing

Springer

BIOLOGICAL AND MEDICAL PHYSICS,
BIOMEDICAL ENGINEERING

For further volumes:
http://www.springer.com/series/3740

BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING

The fields of biological and medical physics and biomedical engineering are broad, multidisciplinary and dynamic. They lie at the crossroads of frontier research in physics, biology, chemistry, and medicine. The Biological and Medical Physics, Biomedical Engineering Series is intended to be comprehensive, covering a broad range of topics important to the study of the physical, chemical and biological sciences. Its goal is to provide scientists and engineers with textbooks, monographs, and reference works to address the growing need for information.

Books in the series emphasize established and emergent areas of science including molecular, membrane, and mathematical biophysics; photosynthetic energy harvesting and conversion; information processing; physical principles of genetics; sensory communications; automata networks, neural networks, and cellular automata. Equally important will be coverage of applied aspects of biological and medical physics and biomedical engineering such as molecular electronic components and devices, biosensors, medicine, imaging, physical principles of renewable energy production, advanced prostheses, and environmental control and engineering.

Thomas M. Deserno
Editor

Biomedical Image Processing

With 254 Figures

Springer

Editor
Dr. Thomas M. Deserno
RWTH Aachen
Institut für Medizinische Informatik
Pauwelsstr. 30
52074 Aachen, Germany
E-mail: deserno@ieee.org

Biological and Medical Physics, Biomedical Engineering ISSN 1618-7210
ISBN 978-3-642-15815-5 e-ISBN 978-3-642-15816-2
DOI 10.1007/978-3-642-15816-2
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2011921516

Cover design: eStudio Calamar Steinen

Printed on acid-free paper

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

To Verena – the beauty and the beauty of images

Preface

YATBIP: Yet another textbook on biomedical image processing? – Hopefully not...

Based on the tutorial *SC086 – Fundamentals of Medical Image Processing* regularly offered at the International SPIE Symposium on Medical Imaging, the Springer-Verlag Series Editor of *Biological and Medical Physics, Medical Engineering* invited me in January 2009 to compile this book. Actually, the idea of providing a "suitable" textbook – comprehensive but short, up-to-date but essential, and detailed but illustrative – for novices like experts, and at reasonable costs, is not new. For years, the lack of any such textbook in image processing covering all of the special needs in biology and medicine is evident. In any teaching lecture, tutorial as well as graduate class. I'm always asked by the students to suggest literature but cannot answer satisfyingly, simply because there isn't a "suitable" textbook yet.

So we aimed at compiling a high-quality collection of chapters, written for scientists, researchers, lectures and graduate students as well, covering the recent advantages in the broad field of biomedical imaging and image processing in an exemplary way. In February 2009, several fruitful discussions with colleagues at SPIE Medical Imaging convinced me to face the challenge, and I started recruiting author teams for contributions. Finally, 47 authors from 11 nations all over the world collaborated – all of them leading experts in their field. Intensive efforts were made to direct all authors towards a similar style of presentation and equal degree of technical details. Beside some written guidelines, the overview chapter was provided to the authors as an example before they started writing. All authors first provided a short outline and a detailed table of content, which were distributed between all contributors together with a strictly enforced time line. In October 2009, submission of chapters started, and each manuscript was edited carefully. Editor requests have been processed by the authors improving completeness and clarity of presentation, and finally in June 2010, the manuscript was submitted to the publisher.

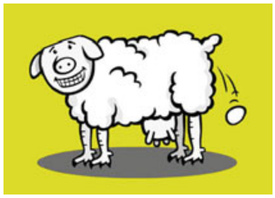

Fig. 1. *Eierlegende Wollmilchsau.* Every morning, this special animal provides a cooked egg with chilled fresh milk. Its wool is used for high-quality clothes and the meat for excellent dining. It is the first *all-in-one* approach documented in history (Courtesy of: `http://neulehrer.wordpress.com/`)

As a result, this book has appeared as uniform monograph with an overview chapter contributed by the editor, followed by some twenty chapters focusing on particular parts selected from biomedical imaging and image processing. Each chapter gives an introduction and overview of recent trends in its field and provides particular case examples, usually taken from the author's own research.

Primarily addressing engineers and system developers in computer sciences, the book covers the entire processing pipeline of biomedical imaging. In particular, the following parts are included, with about three chapters in each of it:

1. Image formation
2. Image enhancement
3. Feature extraction and selection
4. Segmentation
5. Classification and measurements
6. Image data visualization
7. Image management and integration
8. Evaluation and customizing

Many people might object me at this point, because we clearly aimed at reaching the unreachable. In Germany, we have the common phrase "eierlegende Wollmilchsau", a metaphor that directly translates to "egg-providing wool-milk-pig" describing the union of all benefits (Fig. 1).

You as the reader shall judge our success realizing this all-in-one approach: YATBIP or eierlegende Wollmilchsau? Any feedback is deeply welcome and should be directed personally to me as the editor.

Facing now the final manuscript, I want to thank Claus Ascheron for encouraging me to initiate this project, and all contributers for timely delivering their high-quality material and appropriately responding to the editorial remarks and suggestions. Jens Hoffmann was assisting me in LaTeX programming and Max Jung helped in text and image conversion and optimization.

Also, I want to mention Peter Jentsch and Dirk Bartz, who have passed away during the very last iterations of the manuscript, which leaves me behind speechless. We have included the obituaries in the next pages.

Aachen, December 2010 *Thomas M. Deserno, né Lehmann*

Obituaries

Prof. Dr. Peter Jensch died unexpectedly during the period of the proof-reading of this book chapter on April 15, 2010 after a fulfilling life. Peter Jensch was the initiator of the DICOM research activities at the OFFIS - Institute for Information Technology, Oldenburg, Germany, in the early 1990s and was pushing this topic forward for the rest of his life. The most popular result of this engagement is the well-known Open Source DICOM toolkit DCMTK that is hosted and maintained by OFFIS since 1993. Against this background, all members of the DICOM team at OFFIS would like to thank Peter Jensch for establishing this extraordinary project and for being such a likeable, energetic boss, mentor, and colleague to us. Without him, OFFIS would not be the popular name in the world of DICOM it is today and we all would not have such encouraging opportunities and research projects we still enjoy. As Chap. 17 of this book is the last publication Peter Jensch participated in and since the content of this chapter is the very topic that strongly influenced his work, we like to use this opportunity to express our sincere gratitude to Peter Jensch.

Oldenburg, June 2010

Michael Onken
Marco Eichelberg
Jörg Riesmeier

Prof. Dr. Dirk Bartz died unexpectedly on March 28, 2010 while attending the thirtieth Vattenfall Berlin Half Marathon. Running half-marathon in Berlin was one of his favorite activities.

During his academic career, Dirk strongly supported the idea of building a German Interest Group on Medical Visualization and actively took part the whole time giving advice to many students; particularly supporting female researchers was an important issue. Furthermore, Dirk organized many tutorials at Visualization, Eurographics, and Computer-Assisted Radiology and Surgery (CARS).

In 2005, I was very glad that Dirk joined the effort of writing a textbook on “Visualization in Medicine”. For an 18 month period, we communicated daily on the various aspects of the book. It was enlightening and a pleasure to discuss with Dirk all the time. He was always perfectly reliable and good-humored even in situations where he had a very high workload.

In the end of 2006, Dirk became appointed as Full Professor for Computer-Assisted Surgery at the International Center for Computer-Assisted Surgery (ICCAS), Leipzig, Germany, and started to build a new research group. He focused on visualization techniques, such as illustrative rendering, perceptual studies (from Dirk I learned the term “psychophysical studies”), and applications in neurosurgery and Ear, Nose and Throat (ENT) surgery.

Dirk belonged to the core team which tried to establish a new workshop series “Visual Computing in Biology and Medicine”. It was quite natural that Dirk would host the second event, scheduled to take place in July in Leipzig. Until the very last days of his life, he discussed strategies for this workshop.

Dirk was only 42 years old, leaving behind Heidi, his wife, and his two little sons.

Magedeburg, June 2010 *Berhard Preim*

Contents

List of Contributors

Mostafa Analoui
Healthcare and Life Sciences
The Livingston Group
New York, NY, USA
analoui@yahoo.com

Romaric Audigier
Laboratoire Vision et Ingénierie
des Contenus, CEA-LIST
romaric.audigier@cea.fr

Paulo M. Azevedo-Marques
Medical School of Ribeirão Preto
University of São Paulo
São Paulo, Brazil
pmarques@fmrp.usp.br

André G.R. Balan
Computer Science, Mathematics
and Cognition Center
Federal University of ABC
São Paulo, Brazil
agrbalan@icmc.usp.br

Dirk Bartz†
Innovation Center for Computer
Assisted Surgery (ICCAS)
University of Leipzig
Leipzig, Germany

Pedro H. Bugatti
Computer Science Department
University of São Paulo
São Paulo, Brazil
pbugatti@icmc.usp.br

Zang-Hee Cho
Neuroscience Research Institute
Gachon University of Medicine
and Science, Seoul, Korea
zcho@gachon.ac.kr

Krzysztof Chris Ciesielski
Department of Mathematics
West Virginia University
Morgantown, WV, USA

and

Department of Radiology
University of Pennsylvania
Philadelphia, PA, USA
kcies@math.wvu.edu

Lena Costaridou
Department of Medical Physics
University of Patras
Patras, Greece
costarid@upatras.gr

Hervé Delingette
Asclepios Team, INRIA
Sophia-Antipolis, France
herve.delingette@inria.fr

Thomas M. Deserno
Department of Medical Informatics
RWTH Aachen University
Aachen, Germany
deserno@ieee.org

Jan D'hooge
Department of Cardiovascular
Diseases, Katholieke Universiteit
Leuven, Leuven, Belgium
jan.dhooge@uz.kuleuven.ac.be

Jorge Documet
Image Processing and Informatics
Lab, University of Southern
California, Los Angeles, CA, USA
documet@usc.edu

Marco Eichelberg
OFFIS Institute for Information
Technology, Oldenburg, Germany
eichelberg@offis.de

Hayit Greenspan
Department of Biomedical
Enginering, Tel-Aviv University
Tel-Aviv, Israel
hayit@eng.tau.ac.il

Bart M. ter Haar Romeny
Department of Biomedical
Engineering, Eindhoven
University of Technology
Eindhoven, The Netherlands
b.m.terhaarromeny@tue.nl

Tobias Heimann
French Research Institute
of Computer Science and Automatic
Control, INRIA
Sophia Antipolis Cedex, France

and

German Cancer Research Center
Heidelberg, Germany
t.heimann@dkfz.de

Steven C. Horii
Department of Radiology
University of Pennsylvania
Philadelphia PA, USA
steve.horii@uphs.upenn.edu

Alexander Horsch
Department of Medical Statistics
and Epidemiology, Technische
Universität München
Munich, Germany

and

Computer Science Department
University of Tromsø
Tromsø, Norway
alexander.horsch@tum.de

H.K. (Bernie) Huang
Image Processing and Informatics
Lab, University of Southern
California, Los Angeles, CA, USA
hkhuang@aol.com

Peter Jensch†
OFFIS Institute for Information
Technology, Oldenburg, Germany

Jayashree Kalpathy-Cramer
Department of Medical Informatics
and Clinical Epidemiology
Oregon Health & Science University
Portland, OR, USA
kalpathy@ohsu.edu

Young-Bo Kim
Neuroscience Research Institute
Gachon University of Medicine
and Science, Seoul, Korea
neurokim@gachon.ac.kr

Anh HongTu Le
Image Processing and Informatics
Lab, University of Southern
California, Los Angeles, CA, USA
anhhle@usc.edu

Brent J. Liu
Image Processing and Informatics Lab, University of Southern California, Los Angeles, CA, USA
brentliu@usc.edu

Murray H. Loew
Biomedical Engineering Program
Department of Electrical and Computer Engineering
The George Washington University
Washington, DC, USA
loew@gwu.edu

Roberto A. Lotufo
School of Electrical and Computer Engineering, State University of Campinas (UNICAMP)
Campinas, Brazil
lotufo@unicamp.br

Rubens C. Machado
Center for Information Technology Renato Archer (CTI), Ministry of Science and Technology (MCT)
Campinas, Brazil
rubens.machado@cti.gov.br

James G. Malcolm
Department of Psychiatry, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA
malcolm@bwh.harvard.edu

Henning Müller
University of Applied Sciences Western Switzerland (HES-SO)
Sierre, Switzerland

and

University and Hospitals of Geneva
Geneva, Switzerland
henning.mueller@hevs.ch

Michael Onken
OFFIS Institute for Information Technology, Oldenburg, Germany
onken@offis.de

Maria Petrou
Informatics and Telematics Institute
Centre for Research and Technology Hellas (CERTH)
Thessaloniki, Greece
petrou@iti.gr

Bernhard Preim
Department of Simulation and Graphics, University of Magdeburg
Magdeburg, Germany
preim@isg.cs.uni-magdeburg.de

Yogesh Rathi
Department of Psychiatry, Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA
yogesh@bwh.harvard.edu

Marcela X. Ribeiro
Computer Science Department
University of São Paulo
São Paulo, Brazil
mxavier@icmc.usp.br

Jörg Riesmeier
ICSMED AG, Oldenburg, Germany
riesmeier@icsmed.de

Leticia Rittner
School of Electrical and Computer Engineering, State University of Campinas (UNICAMP)
Campinas, Brazil
lrittner@dca.fee.unicamp.br

Daniel Rueckert
Department of Computing, Imperial College London, London, UK
d.rueckert@imperial.ac.uk

André V. Saúde
Department of Computer Science
Federal University of Lavras
Lavras, Minas Gerais, Brazil
saude@dcc.ufla.br

Julia A. Schnabel
Institute of Biomedical Engineering
Department of Engineering
Science, University of Oxford
Oxford, UK
julia.schnabel@eng.ox.ac.uk

Young-Don Son
Neuroscience Research Institute
Gachon University of Medicine
and Science, Seoul, Korea
ydson@gachon.ac.kr

Tanveer Syeda-Mahmood
IBM Almaden Research Center
San Jose, CA, USA
stf@almaden.ibm.com

Agma J.M. Traina
Computer Science Department
University of São Paulo
São Paulo, Brazil
agma@icmc.usp.br

Caetano Traina
Computer Science Department
University of São Paulo
São Paulo, Brazil
caetano@icmc.usp.br

Jayaram K. Udupa
Department of Radiology
University of Pennsylvania
Philadelphia, PA, USA
jay@mail.med.upenn.edu

Carolina Y.V. Watanabe
Computer Science Department
University of São Paulo
São Paulo, Brazil
carolina@icmc.usp.br

Carl-Fredrik Westin
Department of Radiology
Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA
westin@bwh.harvard.edu

Ivo Wolf
Department of Medical Informatics
Mannheim University of Applied
Science, Mannheim, Germany
i.wolf@hs-mannheim.de

Seung-Schik Yoo
Department of Radiology
Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA
yoo@bwh.harvard.edu

Acronyms

1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
4D	Four-Dimensional
AAM	Active Appearance Model
AAPM	American Association of Physicists in Medicine
ABCD	Asymmetry, Border, Color, and Differential structures
ACE	Associative Classifier Engine
ACR	American College of Radiology
ACSE	Association Control Service Element
ADNI	Alzheimer's Disease Neuroimaging Initiative
AE	Application Entity
AFC	Absolute Fuzzy Connectedness
AHA	American Heart Association
AIF	Arterial Input Function
AJAX	Asynchronous Javascript XML
AJCC	American Joint Committee on Cancer
ALM	Acral Lentiginous Melanoma
AMN	Atypical Melanocytic Nevi
ANN	Artificial Neural Network
AOM	Area Overlap Measure
APD	Avalanche Photodiode
API	Application Programming Interface
ASCF	Alternating Sequential Component Filter
ASD	Atrial Septal Defect
ASF	Alternating Sequential Filter
ASM	Active Shape Model
AVD	Absolute Volumetric Difference