Volume 4

Academic Press Library in Signal Processing

Image, Video Processing and Analysis, Hardware, Audio, Acoustic and Speech Processing

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NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SYDNEY • TOKYO

Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
225 Wyman Street, Waltham, MA 02451, USA

First edition 2014

Library of Congress Cataloging in Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-12-396501-1

Printed and bound in Poland.
14 15 16 17 10 9 8 7 6 5 4 3 2 1

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Introduction

Signal Processing at Your Fingertips!

Let us flash back to the 1970s when the editors-in-chief of this e-reference were graduate students. One of the time-honored traditions then was to visit the libraries several times a week to keep track of the latest research findings. After your advisor and teachers, the librarians were your best friends. We visited the engineering and mathematics libraries of our Universities every Friday afternoon and poured over the IEEE Transactions, Annals of Statistics, the Journal of Royal Statistical Society, Biometrika, and other journals so that we could keep track of the recent results published in these journals. Another ritual that was part of these outings was to take sufficient number of coins so that papers of interest could be xeroxed. As there was no Internet, one would often request copies of reprints from authors by mailing postcards and most authors would oblige. Our generation maintained thick folders of hard-copies of papers. Prof. Azriel Rosenfeld (one of RC's mentors) maintained a library of over 30,000 papers going back to the early 1950s!

Another fact to recall is that in the absence of Internet, research results were not so widely disseminated then and even if they were, there was a delay between when the results were published in technologically advanced western countries and when these results were known to scientists in third world countries. For example, till the late 1990s, scientists in US and most countries in Europe had a lead time of at least a year to 18 months since it took that much time for papers to appear in journals after submission. Add to this the time it took for the Transactions to go by surface mails to various libraries in the world. Scientists who lived and worked in the more prosperous countries were aware of the progress in their fields by visiting each other or attending conferences.

Let us race back to 21st century! We live and experience a world which is fast changing with rates unseen before in the human history. The era of Information and Knowledge societies had an impact on all aspects of our social as well as personal lives. In many ways, it has changed the way we experience and understand the world around us; that is, the way we learn. Such a change is much more obvious to the younger generation, which carries much less momentum from the past, compared to us, the older generation. A generation which has grew up in the Internet age, the age of Images and Video games, the age of IPAD and Kindle, the age of the fast exchange of information. These new technologies comprise a part of their "real" world, and Education and Learning can no more ignore this reality. Although many questions are still open for discussions among sociologists, one thing is certain. Electronic publishing and dissemination, embodying new technologies, is here to stay. This is the only way that effective pedagogic tools can be developed and used to assist the learning process from now on. Many kids in the early school or even preschool years have their own IPADs to access information in the Internet. When they grow up to study engineering, science, or medicine or law, we doubt if they ever will visit a library as they would by then expect all information to be available at their fingertips, literally!

Another consequence of this development is the leveling of the playing field. Many institutions in lesser developed countries could not afford to buy the IEEE Transactions and other journals of repute. Even if they did, given the time between submission and publication of papers in journals and the time it took for the Transactions to be sent over surface mails, scientists and engineers in lesser developed countries were behind by two years or so. Also, most libraries did not acquire the proceedings of conferences and so there was a huge gap in the awareness of what was going on in technologically advanced

countries. The lucky few who could visit US and some countries in Europe were able to keep up with the progress in these countries. This has changed. Anyone with an Internet connection can request or download papers from the sites of scientists. Thus there is a leveling of the playing field which will lead to more scientist and engineers being groomed all over the world.

The aim of Online Reference for Signal Processing project is to implement such a vision. We all know that asking any of our students to search for information, the first step for him/her will be to click on the web and possibly in the Wikipedia. This was the inspiration for our project. To develop a site, related to the Signal Processing, where a selected set of reviewed articles will become available at a first "click." However, these articles are fully refereed and written by experts in the respected topic. Moreover, the authors will have the "luxury" to update their articles regularly, so that to keep up with the advances that take place as time evolves. This will have a double benefit. Such articles, besides the more classical material, will also convey the most recent results providing the students/researchers with up-to-date information. In addition, the authors will have the chance of making their article a more "permanent" source of reference, that keeps up its freshness in spite of the passing time.

The other major advantage is that authors have the chance to provide, alongside their chapters, any multimedia tool in order to clarify concepts as well as to demonstrate more vividly the performance of various methods, in addition to the static figures and tables. Such tools can be updated at the author's will, building upon previous experience and comments. We do hope that, in future editions, this aspect of this project will be further enriched and strengthened.

In the previously stated context, the Online Reference in Signal Processing provides a revolutionary way of accessing, updating and interacting with online content. In particular, the Online Reference will be a living, highly structured, and searchable peer-reviewed electronic reference in signal/image/video Processing and related applications, using existing books and newly commissioned content, which gives tutorial overviews of the latest technologies and research, key equations, algorithms, applications, standards, code, core principles, and links to key Elsevier journal articles and abstracts of non-Elsevier journals.

The audience of the Online Reference in Signal Processing is intended to include practicing engineers in signal/image processing and applications, researchers, PhD students, post Docs, consultants, and policy makers in governments. In particular, the readers can be benefited in the following needs:

- To learn about new areas outside their own expertise.
- To understand how their area of research is connected to other areas outside their expertise.
- To learn how different areas are interconnected and impact on each other: the need for a "helicopter" perspective that shows the "wood for the trees."
- To keep up-to-date with new technologies as they develop: what they are about, what is their potential, what are the research issues that need to be resolved, and how can they be used.
- To find the best and most appropriate journal papers and keeping up-to-date with the newest, best papers as they are written.
- To link principles to the new technologies.

The Signal Processing topics have been divided into a number of subtopics, which have also dictated the way the different articles have been compiled together. Each one of the subtopics has been coordinated by an AE (Associate Editor). In particular:

1. Signal Processing Theory (Prof. P. Diniz)
2. Machine Learning (Prof. J. Suykens)
3. DSP for Communications (Prof. N. Sidiropulos)
4. Radar Signal Processing (Prof. F. Gini)
5. Statistical SP (Prof. A. Zoubir)
6. Array Signal Processing (Prof. M. Viberg)
7. Image Enhancement and Restoration (Prof. H. J. Trussell)
8. Image Analysis and Recognition (Prof. Anuj Srivastava)
9. Video Processing (other than compression), Tracking, Super Resolution, Motion Estimation, etc. (Prof. A. R. Chowdhury)
10. Hardware and Software for Signal Processing Applications (Prof. Ankur Srivastava)
11. Speech Processing/Audio Processing (Prof. P. Naylor)
12. Still Image Compression
13. Video Compression

We would like to thank all the Associate Editors for all the time and effort in inviting authors as well as coordinating the reviewing process. The Associate Editors have also provided succinct summaries of their areas.

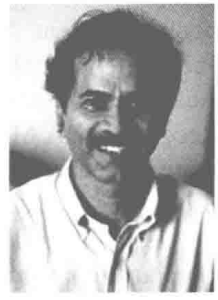
The articles included in the current editions comprise the first phase of the project. In the second phase, besides the updates of the current articles, more articles will be included to further enrich the existing number of topics. Also, we envisage that, in the future editions, besides the scientific articles we are going to be able to include articles of historical value. Signal Processing has now reached an age that its history has to be traced back and written.

Last but not least, we would like to thank all the authors for their effort to contribute in this new and exciting project. We earnestly hope that in the area of Signal Processing, this reference will help level the playing field by highlighting the research progress made in a timely and accessible manner to anyone who has access to the Internet. With this effort the next breakthrough advances may be coming from all around the world.

The companion site for this work: http://booksite.elsevier.com/9780124166165 includes multimedia files (Video/Audio) and MATLAB codes for selected chapters.

Rama Chellappa
Sergios Theodoridis

About the Editors



Rama Chellappa received the B.E. (Hons.) degree in Electronics and Communication Engineering from the University of Madras, India in 1975 and the M.E. (with Distinction) degree from the Indian Institute of Science, Bangalore, India in 1977. He received the M.S.E.E. and Ph.D. Degrees in Electrical Engineering from Purdue University, West Lafayette, IN, in 1978 and 1981, respectively. During 1981–1991, he was a faculty member in the department of EE-Systems at University of Southern California (USC). Since 1991, he has been a Professor of Electrical and Computer Engineering (ECE) and an affiliate Professor of Computer Science at University of Maryland (UMD), College Park. He is also affiliated with the Center for Automation Research, the Institute for Advanced Computer Studies (Permanent Member) and is serving as the Chair of the ECE department. In 2005, he was named a Minta Martin Professor of Engineering. His current research interests are face recognition, clustering and video summarization, 3D modeling from video, image and video-based recognition of objects, events and activities, dictionary-based inference, compressive sensing, domain adaptation and hyper spectral processing.

Prof. Chellappa received an NSF Presidential Young Investigator Award, four IBM Faculty Development Awards, an Excellence in Teaching Award from the School of Engineering at USC, and two paper awards from the International Association of Pattern Recognition (IAPR). He is a recipient of the K.S. Fu Prize from IAPR. He received the Society, Technical Achievement, and Meritorious Service Awards from the IEEE Signal Processing Society. He also received the Technical Achievement and Meritorious Service Awards from the IEEE Computer Society. At UMD, he was elected as a Distinguished Faculty Research Fellow, as a Distinguished Scholar-Teacher, received an Outstanding Innovator Award from the Office of Technology Commercialization, and an Outstanding GEMSTONE Mentor Award from the Honors College. He received the Outstanding Faculty Research Award and the Poole and Kent Teaching Award for Senior Faculty from the College of Engineering. In 2010, he was recognized as an Outstanding ECE by Purdue University. He is a Fellow of IEEE, IAPR, OSA, and AAAS. He holds four patents.

Prof. Chellappa served as the Editor-in-Chief of IEEE Transactions on Pattern Analysis and Machine Intelligence. He has served as a General and Technical Program Chair for several IEEE international and national conferences and workshops. He is a Golden Core Member of the IEEE Computer Society and served as a Distinguished Lecturer of the IEEE Signal Processing Society. Recently, he completed a two-year term as the President of the IEEE Biometrics Council.

Sergios Theodoridis is currently Professor of Signal Processing and Communications in the Department of Informatics and Telecommunications of the University of Athens. His research interests lie in the areas of Adaptive Algorithms and Communications, Machine Learning and Pattern Recognition, Signal Processing for Audio Processing and Retrieval. He is the co-editor of the book "Efficient Algorithms for Signal Processing and System Identification," Prentice Hall 1993, the co-author of the best selling book "Pattern Recognition," Academic Press, 4th ed. 2008, the co-author of the book "Introduction to Pattern Recognition: A MATLAB Approach," Academic Press, 2009, and the co-author of three books in Greek, two of them for the Greek Open University. He is Editor-in-Chief for the Signal Processing Book Series, Academic Press and for the E-Reference Signal Processing, Elsevier.

He is the co-author of six papers that have received best paper awards including the 2009 IEEE Computational Intelligence Society Transactions on Neural Networks Outstanding paper Award. He has served as an IEEE Signal Processing Society Distinguished Lecturer. He was *Otto Monstead Guest* Professor, Technical University of Denmark, 2012, and holder of *the Excellence Chair*, Department of Signal Processing and Communications, University Carlos III, Madrid, Spain, 2011.

He was the General Chairman of EUSIPCO-98, the Technical Program co-Chair for ISCAS-2006 and ISCAS-2013, and co-Chairman and co-Founder of CIP-2008 and co-Chairman of CIP-2010. He has served as President of the European Association for Signal Processing (EURASIP) and as member of the Board of Governors for the IEEE CAS Society. He currently serves as member of the Board of Governors (Member-at-Large) of the IEEE SP Society.

He has served as a member of the Greek National Council for Research and Technology and he was Chairman of the SP advisory committee for the Edinburgh Research Partnership (ERP). He has served as Vice Chairman of the Greek Pedagogical Institute and he was for 4 years member of the Board of Directors of COSMOTE (the Greek mobile phone operating company). He is Fellow of IET, a Corresponding Fellow of the Royal Society of Edinburgh (RSE), a Fellow of EURASIP, and a Fellow of IEEE.

Section Editors

Section 1

Joel Trussell received degrees from Georgia Tech (B.S.), Florida State (M.S.), and the University of New Mexico (Ph.D.). He joined the Los Alamos Scientific Laboratory, Los Alamos, NM, in 1969 where he began working in the image and signal processing in 1971. During 1978–1979, he was a Visiting Professor at Heriot-Watt University, Edinburgh, Scotland where he worked with both the university and with industry on image processing problems. In 1980, he joined the Electrical and Computer Engineering Department at North Carolina State University, Raleigh, NC, where he is now a Professor. During 1988–1989, he was a visiting scientist at the Eastman Kodak Company in Rochester, NY and 1997–1998 was a visiting scientist at Color Savvy Systems in Springboro, OH. He was a Visiting Fellow Commoner at Trinity College Cambridge University in 2007 and a visiting scientist with Hewlett-Packard Labs in 2008. From 2002 to 2010, he served as Director of Graduate Programs for the ECE Department. He is a past associate editor for the Transactions on ASSP and the Signal Processing Letters. He is a past Chairman of and long serving on the Image and Multidimensional Digital Signal Processing Committee of the Signal Processing Society of the IEEE. He is Fellow of the IEEE and has shared the IEEE-ASSP Society Senior Paper Award (1986 with M.R. Civanlar) and the IEEE-SP Society Paper Award (1993 with P.L. Combettes). He is the author of two texts: Fundamentals of Digital Imaging (with M.J. Vrhel) and Mathematics: The Language of Electrical and Computer Engineering (with Y. Viniotis).

Section 2

Anuj Srivastava is a professor in the Department of Statistics, Florida State University. He obtained M.S. and Ph.D. degrees in electrical engineering from Washington University in St. Louis, in the years 1993 and 1996, respectively. During 1996-97, he was a visiting research scientist at the Division of Applied Mathematics, Brown University, working with Prof. Ulf Grenander. In Fall 1997, he joined the Department of Statistics at the Florida State University as an assistant professor. During 2003-2006, he was an associate professor there, and later in 2007 he became a professor. He has held visiting positions at the University of Lille, France and INRIA, Sophia Antipolis, France.

He was awarded FSU's Developing Scholar Award in 2005 and the Graduate Mentor Faulty Award in 2008.

Section 3

Amit K. Roy-Chowdhury received his Masters degree in systems science and automation from the Indian Institute of Science, Bangalore, India, and the Ph.D. degree in electrical engineering from the University of Maryland, College Park. He is a Professor of electrical engineering and a Cooperating Faculty in the Department of Computer Science, University of California, Riverside. His broad

research interests include the areas of image processing and analysis, computer vision, and statistical signal processing and pattern recognition, where he has over 100 technical publications. His current research projects include intelligent camera networks, wide-area scene analysis, motion analysis in video, activity recognition and search, video-based biometrics (face and gait), and biological video analysis. He is a coauthor of two books - Camera Networks: The Acquisition and Analysis of Videos over Wide Areas and Recognition of Humans and Their Activities Using Video. He has been on the organizing and program committees of multiple computer vision and image processing conferences and is serving on the editorial boards of multiple journals.

Section 4

Ankur Srivastava received the B.S. degree in technology and electrical engineering from the Indian Institute of Technology Delhi, India, the M.S. degree in computer engineering from the Department of Electrical and Computer Engineering (ECE), Northwestern University, Evanston, IL, and the Ph.D. degree from the Computer Science, University of California, Los Angeles (UCLA), in 1998, 2000, and 2002, respectively.

He is currently an Associate Professor with the ECE Department, University of Maryland, College Park, where he has been since 2002, with a joint appointment with the Institute for Systems Research. His current research interests include design methods and runtime control policies for high-performance, low temperature, and low-power VLSI circuits. Dr. Srivastava was a recipient of the Outstanding Ph.D. Award from the Computer Science of UCLA and the George Corcoran Memorial Outstanding Teaching Award by the ECE Department, University of Maryland. His work has been recognized through several best paper awards and nominations, including ICCAD 2003, ISPD 2007, AHS 2011, ISVLSI 2012, and DAC 2012.

Sections 5, 6 and 7

Patrick A. Naylor received his B.Eng. degree in Electronic and Electrical Engineering from the University of Sheffield, UK, in 1986 and the Ph.D. degree from Imperial College, London, UK, in 1990. Since 1990 he has been a member of academic staff in the Department of Electrical and Electronic Engineering at Imperial College London. His research interests are in the areas of speech, audio and acoustic signal processing. He has worked in particular on adaptive signal processing for dereverberation, blind multichannel system identification and equalization, acoustic echo control, speech quality estimation and classification, single and multichannel speech enhancement, and speech production modeling with particular focus on the analysis of the voice source signal. In addition to his academic research, he enjoys several fruitful links with industry in the UK, USA, and in mainland Europe. He is an associate editor of IEEE Transactions on Audio Speech and Language Processing and an associate member of the IEEE Signal Processing Society Technical Committee on Audio and Acoustic Signal Processing.

Authors Biography

CHAPTER 2

Bruce H. Pillman is a senior image scientist with ITT Exelis Geospatial Systems, working on leading edge imaging and information systems. Prior to taking a position with Exelis, he was at the Kodak Research Laboratories as a senior principal scientist, working on still and video imaging. Main topics of his work included measurement, modeling, and psychometric analysis of still and video imagery, automatic scene classification, psychometric still image and video quality modeling, and flexible image capture in the presence of motion. He has also been involved in the research and development of chemical processes and process control systems, film scanning and image enhancement, and digital camera image processing, including camera calibration, sensor artifact correction, noise reduction, automatic white balance, and overall image processing chain design. He holds 35 patents, mostly related to digital camera technology, and has written several articles and book chapters. He has a B.S. in Chemical Engineering (1982) from Northwestern University in Illinois, and an M.S. in Electrical Engineering (1992) from the University of Rochester, NY.

James E. Adams, Jr. is a senior principal scientist at the Kodak Research Laboratories. He holds 49 patents in the field of digital image processing, most notably in the fields of color filter array interpolation and noise reduction. He is a Kodak Distinguished Inventor, winner of the Eastman Innovation Award, and the 2005 Rochester Inventor of the Year. He has authored several technical articles and book chapters on all aspects of digital camera image processing. A number of his publications are considered seminal works and have been cited hundreds of times. He has a B.S. in Physics (1979) from Monmouth College, NJ, and an M.S. in Optics (1983) from the University of Rochester, NY. Since joining Eastman Kodak Company in 1979, he has been involved in the research and design of innovative optical test fixtures, satellite-based laser communication systems as part of the Strategic Defense Initiative, new optical radiation measurement devices for decoupling the effects of fluorescence from other material optical properties, and most aspects of digital camera image processing, mostly notable color filter array design and interpolation, noise reduction, automatic white balance, and overall image processing chain design. He is currently working in the areas of video refocusing, super-resolution, and other computational video photography topics.

CHAPTER 3

Kathrin Berkner leads the Computation Optics & Visual Processing Group at the California Innovation Center of Ricoh Innovations where she is responsible for creating innovative technology for computational imaging systems for computer and human vision applications, starting from digital-optical co-design of optics and signal processing algorithms via prototyping to transferring the innovative concepts into Ricoh's products.

Previously, she was a Senior Research Scientist at Ricoh Innovations, conducting research in a variety of imaging areas related to restoration and enhancement of images, reformatting of documents, and adaptation of documents to small-size displays. Her wavelet-based document enhancement technology for Ricoh's MFP products was awarded the Ricoh Minori Award for outstanding creativity.

Prior to joining Ricoh in 1998, she was a Postdoctoral Researcher at Rice University, Houston, TX, performing research on wavelets in collaboration with the Rice DSP group. She holds a Ph.D. degree in Mathematics from the University of Bremen, Germany. She has been serving on program committees and as a reviewer of several IS&T/SPIE, IEEE, ACM, and OSA conferences and journals. She has authored more than 20 technical publications, and has over 30 patents granted or pending.

Her interests include soccer, team handball, and playing violin in the Redwood Symphony orchestra.

CHAPTER 4

Oscar C. Au received his B.A.Sc. from University of Toronto in 1986, his M.A. and Ph.D. from Princeton University in 1988 and 1991, respectively. After being a postdoctoral researcher in Princeton University for one year, he joined the Hong Kong University of Science and Technology (HKUST) as an Assistant Professor in 1992. He is/has been a Professor of the Department of Electronic and Computer Engineering, Director of Multimedia Technology Research Center (MTrec), and Director of the Computer Engineering (CPEG) Program in HKUST.

His main research contributions are on video and image coding and processing, watermarking and light weight encryption, speech and audio processing. Research topics include fast motion estimation for MPEG-1/2/4, H.261/3/4 and AVS, optimal and fast suboptimal rate control, mode decision, transcoding, denoising, deinterlacing, post-processing, multiview coding, scalable video coding, distributed video coding, subpixel rendering, JPEG/JPEG2000, HDR imaging, compressive sensing, halftone image data hiding, GPU-processing, software-hardware co-design, etc. He has published about 320 technical journals and conference papers. His fast motion estimation algorithms were accepted into the ISO/IEC 14496-7 MPEG-4 international video coding standard and the China AVS-M standard. His light-weight encryption and error resilience algorithms are accepted into the China AVS standard. He has 8 US patents and is applying for 60+ more on his signal processing techniques. He has performed forensic investigation and stood as an expert witness in the Hong Kong courts many times.

He is an active senior member of the Institute of Electrical and Electronic Engineering (IEEE) and is a Board of Governor member of the Asia Pacific Signal and Information Processing Association (APSIPA). He is/was Associate Editors of IEEE Transactions on Circuits and Systems for Video Technology (TCSVT), IEEE Transactions on Image Processing (TIP), and IEEE

Transactions on Circuits and Systems, Part 1 (TCAS1). He is on the Editorial Boards of Journal of Signal Processing Systems, Journal of Multimedia, and Journal of Franklin Institute. He is/was Chair of CAS Technical Committee on Multimedia Systems and Applications (MSATC), Vice Chair of SP TC on Multimedia Signal Processing (MMSP), and a member of CAS TC on Video Signal Processing and Communications (VSPC), CAS TC on DSP, and SP TC on Image, Video and Multidimensional Signal Processing (IVMSP). He served on the Steering Committee of IEEE Transactions on Multimedia (TMM), and IEEE International Conference of Multimedia and Expo (ICME). He also served on the organizing committee of IEEE Int. Symposium on Circuits and Systems (ISCAS) in 1997, IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) in 2003, the ISO/IEC MPEG 71st Meeting in 2005, International Conference on Image Processing (ICIP) in 2010, and other conferences. He was General Chair of Pacific-Rim Conference on Multimedia (PCM) in 2007, IEEE International Conference on Multimedia and Expo (ICME) in 2010 and Packet Video Workshop (PV) in 2010. He won best paper awards in SiPS 2007 and PCM 2007. He is an IEEE Distinguished Lecturer (DLP) in 2009 and 2010, and has been keynote speaker for a few times.

Lu Fang received the B.S. degree in 2007 from the Department of Electronic Engineering and Information Science, University of Science and Technology of China (USTC), Hefei, China. She received Ph.D. degree in 2011 from the Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology (HKUST), Hong Kong. She used to visit Northwestern University under the support of Professor Aggelos K. Katsaggelos in 2012. From 2011 to 2012, she was the post-doc research fellow in HKUST and Singapore University of Technology and Design (SUTD), respectively. She is currently an Associate Professor in University of Science and Technology of China (USTC), with research interests in Multimedia Processing, 3D Video Analysis and Coding, Machine Learning, etc.

CHAPTER 5

Philipp Urban has been Head of an Emmy-Noether research group at the Technische Universitat Darmstadt (Germany) since 2009. His research focuses on color science and spectral imaging. From 2006 to 2008 he was a visiting scientist at the RIT Munsell Color Science Laboratory. He holds a M.S. in Mathematics from the University of Hamburg and a Ph.D. from the Hamburg University of Technology (Germany).

Simon Stahl received his diploma degree in Mechanical Engineering at the Technische Universität Darmstadt in 2009. Since then he is working as a Ph.D. student at the Institute of Printing Science and Technology of TU Darmstadt. He is a part of the functional printing team, with research topics of material characterization and gravure printing.

Edgar Dorsam has been full Professor and Director of the Institute of Printing Science and Technology at the Technische Universität Darmstadt, Germany since 2003. From 1994 to 2003 he was responsible for research and development at MAN Roland AG in O®enbach, Germany. He has more than 30 patents and is member of IS&T, VDD, VDI, and OE-A. He holds a M.S. and a doctoral degree in Mechanical Engineering from Technische Universität Darmstadt.

CHAPTER 6

Stanley J. Reeves received the PhD in 1990 from the Georgia Institute of Technology. He is a professor in the Department of Electrical and Computer Engineering at Auburn University. He has served as associate editor for IEEE Transactions on Image Processing, IEEE Transactions on Image Processing, and IEEE Signal Processing Letters. He has also served on the Signal Processing Theory and Methods Technical Committee of the IEEE Signal Processing Society. His interests include digital signal processing, image restoration and reconstruction, optimal image acquisition, medical imaging, and color and spectral imaging.

CHAPTER 7

Sebastian Berisha is a Ph.D. student in Computer Science at Emory University. He received his M.S. degree in Computer Science from Wake Forest University in 2009, and a B.S. degree from Averett University in 2006. His research interests include numerical linear algebra, image processing, and high performance computing.

James G. Nagy is a Professor of Mathematics and Computer Science at Emory University. He received his Ph.D. in Applied Mathematics from North Carolina State University in 1991. Before joining Emory University in 1999 he had postdoctoral research fellowships with the IMA at the