PROCEEDINGS OF SPIE

SPIDigitalLibrary.org/conference-proceedings-of-spie

Front Matter: Volume 8657

, "Front Matter: Volume 8657," Proc. SPIE 8657, Computational Imaging XI, 865701 (25 February 2013); doi: 10.1117/12.2021498

SPIE.

Event: IS&T/SPIE Electronic Imaging, 2013, Burlingame, California, United States

Computational Imaging XI

Charles A. Bouman
Ilya Pollak
Patrick J. Wolfe
Editors

5–7 February 2013
Burlingame, California, United States

Sponsored by
IS&T—The Society for Imaging Science and Technology
SPIE

Cosponsored by
Qualcomm Inc. (United States)

Published by
SPIE

Volume 8657

Proceedings of SPIE 0277-786X, V.8657

Computational Imaging XI, edited by Charles A. Bouman, Ilya Pollak, Patrick J. Wolfe,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 8657, 865701 • © 2013 SPIE-IS&T
CCC code: 0277-786X/13/\$18 • doi: 10.1117/12.2021498

SPIE-IS&T/ Vol. 8657 865701-1

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publishers are not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:

Author(s), "Title of Paper," in *Computational Imaging XI*, edited by Charles A. Bouman, Ilya Pollak, Patrick J. Wolfe, Proceedings of SPIE-IS&T Electronic Imaging, SPIE Vol. 8657. Article CID Number (2013)

ISSN: 0277-786X

ISBN: 9780819494306

Copublished by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445

SPIE.org

and

IS&T—The Society for Imaging Science and Technology

7003 Kilworth Lane, Springfield, Virginia, 22151 USA

Telephone +1 703 642 9090 (Eastern Time) · Fax +1 703 642 9094

imaging.org

Copyright © 2013, Society of Photo-Optical Instrumentation Engineers and The Society for Imaging Science and Technology.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by the publishers subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/13/\$18.00.

Printed in the United States of America.

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc.

The CID Number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID Number.

Contents

- vii Conference Committee
- ix Presentation slides from "A forward modeling approach to electron back-scatter diffraction patterns" M. De Graef, Carnegie Mellon Univ. (United States)

COMPUTATIONAL PHOTOGRAPHY

- 8657 02 **A unifying retinex model based on non-local differential operators** [8657-1]
D. Zosso, G. Tran, S. Osher, The Univ. of California, Los Angeles (United States)
- 8657 03 **Subspace methods for computational relighting** [8657-2]
H. Q. Nguyen, S. Liu, M. N. Do, Univ. of Illinois at Urbana-Champaign (United States)
- 8657 04 **Bayesian demosaicing using Gaussian scale mixture priors with local adaptivity in the dual tree complex wavelet packet transform domain** [8657-3]
B. Goossens, J. Aelterman, H. Luong, A. Pizurica, W. Philips, Ghent Univ. (Belgium)
- 8657 05 **Demosaicing for RGBZ sensor** [8657-4]
L. Shi, I. Ovsianikov, Samsung Semiconductor Inc. (United States); D.-K. Min, Y. Noh, W. Kim, S. Jung, J. Lee, D. Shin, H. Jung, Semiconductor R&D Ctr. (Korea, Republic of); G. Waligorski, Y. M. Wang, W. Wang, Samsung Semiconductor Inc. (United States); Y. Park, C. Chung, Semiconductor R&D Ctr. (Korea, Republic of)
- 8657 06 **Auto zoom crop from face detection and facial features** [8657-5]
R. Ptucha, D. Rhoda, B. Mittelstaedt, Eastman Kodak Co. (United States)

COMPRESSED SENSING AND CODED APERTURE IMAGING

- 8657 07 **Optimal filters for high-speed compressive detection in spectroscopy** [8657-6]
G. T. Buzzard, B. J. Lucier, Purdue Univ. (United States)
- 8657 08 **Neutron imaging with coded sources: design pitfalls and the implementation of a simultaneous iterative reconstruction technique** [8657-8]
H. J. Santos-Villalobos, P. R. Bingham, Oak Ridge National Lab. (United States); J. Gregor, Univ. of Tennessee (United States)

PHYSICS-BASED MICROSCOPIC IMAGING I

- 8657 0A **Model based iterative reconstruction for Bright Field electron tomography** [8657-11]
S. V. Venkatakrishnan, Purdue Univ. (United States); L. F. Drummy, Air Force Research Lab. (United States); M. De Graef, Carnegie Mellon Univ. (United States); J. P. Simmons, Air Force Research Lab. (United States); C. A. Bouman, Purdue Univ. (United States)

KEYNOTE SESSION I

- 8657 0B **Petapixel photography and the limits of camera information capacity (Keynote Paper)** [8657-35]
D. J. Brady, D. L. Marks, S. Feller, Duke Univ. (United States); M. Gehm, D. Golish, E. Vera, The Univ. of Arizona (United States); D. Kittle, Duke Univ. (United States)

PHYSICS-BASED MICROSCOPIC IMAGING II

- 8657 0C **Sparse imaging for fast electron microscopy** [8657-12]
H. S. Anderson, J. Ilic-Helms, B. Rohrer, J. Wheeler, K. Larson, Sandia National Labs. (United States)
- 8657 0D **Building and enforcing shape priors for segmentation of alloy micrographs** [8657-13]
L. M. Huffman, The MITRE Corp. (United States); J. P. Simmons, Air Force Research Lab. (United States); M. De Graef, Carnegie Mellon Univ. (United States); I. Pollak, Purdue Univ. (United States)

PHYSICS-BASED MICROSCOPIC IMAGING III

- 8657 0E **Real-time dynamic range and signal to noise enhancement in beam-scanning microscopy by integration of sensor characteristics, data acquisition hardware, and statistical methods** [8657-14]
D. J. Kissick, R. D. Muir, S. Z. Sullivan, R. A. Oglesbee, G. J. Simpson, Purdue Univ. (United States)
- 8657 0G **Segmentation of materials images using 3D electron interaction modeling** [8657-16]
D. Kim, M. L. Comer, Purdue Univ. (United States)
- 8657 0I **Interactive grain image segmentation using graph cut algorithms** [8657-18]
J. Waggoner, Y. Zhou, Univ. of South Carolina (United States); J. Simmons, Air Force Research Lab. (United States); A. Salem, Materials Resources, LLC (United States); M. De Graef, Carnegie Mellon Univ. (United States); S. Wang, Univ. of South Carolina (United States)

SEGMENTATION AND TRACKING

- 8657 0J **An enhanced grid-based Bayesian array for target tracking** [8657-19]
Q. Sang, Z. Lin, S. T. Acton, Univ. of Virginia (United States)
- 8657 0L **Efficient occlusion reasoning for articulated tracking in monocular views** [8657-21]
L. M. Huffman, The MITRE Corp. (United States); I. Pollak, Purdue Univ. (United States)
- 8657 0M **An efficient optimizer for simple point process models** [8657-22]
A. Gamal-Eldin, INRIA Sophia Antipolis (France) and INRIA Rhone Alpes (France); G. Charpiat, X. Descombes, J. Zerubia, INRIA Sophia Antipolis (France)

IMAGE SYSTEM MODELING AND SIMULATION

- 8657 00 **Optical touch sensing: practical bounds for design and performance** [8657-24]
A. Bläbkle, Univ. of British Columbia Okanagan (Canada); B. Janbek, Simon Fraser Univ. (Canada); L. Liu, Univ. of Pittsburgh (United States); K. Nakamura, Univ. of Maryland, College Park (United States); K. Nolan, Drexel Univ. (United States); V. Paraschiv, Univ. of Victoria (Canada)

RECONSTRUCTION, INVERSE PROBLEMS, AND NOISE REDUCTION I

- 8657 0P **Light field image denoising using a linear 4D frequency-hyperfan all-in-focus filter** [8657-25]
D. G. Dansereau, D. L. Bongiorno, O. Pizarro, S. B. Williams, The Univ. of Sydney (Australia)
- 8657 0R **Robust registration of electron tomography projections without fiducial markers** [8657-27]
V.-D. Tran, IFP Energies Nouvelles (France) and Lab. Hubert Curien, CNRS, Univ. de Saint-Etienne (France); M. Moreaud, IFP Energies Nouvelles (France); É. Thiébaud, Observatoire de Lyon, CNRS, Univ. de Lyon (France); L. Denis, J.-M. Becker, Lab. Hubert Curien, CNRS, Univ. de Saint-Etienne (France)

RECONSTRUCTION, INVERSE PROBLEMS, AND NOISE REDUCTION II

- 8657 0S **Statistical modeling challenges in model-based reconstruction for x-ray CT** [8657-28]
R. Zhang, Purdue Univ. (United States); A. Chang, Univ. of Notre Dame (United States); J.-B. Thibault, GE Healthcare (United States); K. Sauer, Univ. of Notre Dame (United States); C. Bouman, Purdue Univ. (United States)
- 8657 0T **Joint reconstruction and segmentation of electron tomography data** [8657-29]
A. Tuysuzoglu, W. C. Karl, D. Castanon, M. S. Unlu, Boston Univ. (United States)
- 8657 0U **Analysis of image color and effective bandwidth as a tool for assessing air pollution at urban spatiotemporal scale** [8657-30]
Y. Etzion, D. M. Broday, B. Fishbain, Technion - Israel Institute of Technology (Israel)

INTERACTIVE PAPER SESSION

- 8657 0W **Efficient synthetic refocusing method from multiple coded aperture images for 3D user interaction** [8657-32]
S. Suh, C. Choi, D. Park, C. Kim, Samsung Advanced Institute of Technology (Korea, Republic of)
- 8657 0X **Multiscale based adaptive contrast enhancement** [8657-33]
M. Abir, F. Islam, Missouri Univ. of Science and Technology (United States); D. Wachs, Idaho National Lab. (United States); H. Lee, Missouri Univ. of Science and Technology (United States)

Author Index

Conference Committee

Symposium Chair

Gaurav Sharma, University of Rochester (United States)

Symposium Cochair

Sergio R. Goma, Qualcomm Inc. (United States)

Conference Chairs

Charles A. Bouman, Purdue University (United States)

Ilya Pollak, Purdue University (United States)

Patrick J. Wolfe, Harvard University (United States)

Conference Program Committee

Scott T. Acton, University of Virginia (United States)

Thomas S. Denney Jr., Auburn University (United States)

Minh N. Do, University of Illinois at Urbana-Champaign (United States)

Peter C. Doerschuk, Cornell University (United States)

Maya R. Gupta, University of Washington (United States)

William C. Karl, Boston University (United States)

Eric L. Miller, Tufts University (United States)

Joseph A. O'Sullivan, Washington University in St. Louis (United States)

Zygmunt Pizlo, Purdue University (United States)

Stanley J. Reeves, Auburn University (United States)

Jeff P. Simmons, Air Force Research Laboratory (United States)

Yongyi Yang, Illinois Institute of Technology (United States)

Session Chairs

Computational Photography

Charles A. Bouman, Purdue University (United States)

Compressed Sensing and Coded Aperture Imaging

Bradley J. Lucier, Purdue University (United States)

Physics-Based Microscopic Imaging I

Marc De Graef, Carnegie Mellon University (United States)

Keynote Session I

Charles A. Bouman, Purdue University (United States)

Physics-Based Microscopic Imaging II
William C. Karl, Boston University (United States)

Physics-Based Microscopic Imaging III
Mary L. Comer, Purdue University (United States)

Segmentation and Tracking
Landis M. Huffman, Purdue University (United States)

Image System Modeling and Simulation
Singanallur Venkatakrishnan, Purdue University (United States)

Reconstruction, Inverse Problems, and Noise Reduction I
Joseph A. O'Sullivan, Washington University in St. Louis (United States)

Reconstruction, Inverse Problems, and Noise Reduction II
Ken D. Sauer, University of Notre Dame (United States)

Imaging

Diffraction

Spectroscopy

*A forward modeling approach to
electron back-scatter diffraction patterns*

Marc DeGraef

Carnegie Mellon University

SPIE, 2/6/13, 8657-17

Wednesday, February 13, 13

1

Funding Sources

- ◆ ONR ONR N00014-12-1-0075
- ◆ MURI AFOSR-FA9550-12-1-0458
- ◆ Electronic Imaging component of the ICMD program of the Materials and Manufacturing Directorate (AFRL)

Wednesday, February 13, 13

2

Outline

- ◆ Background on EBSD
- ◆ Geometry and special projections
- ◆ Dynamical simulations
- ◆ What's next?
- ◆ Summary

Wednesday, February 13, 13

3

Lots of electron diffraction modalities ...

There's only one theory that underlies all of these modalities ...

X

Wednesday, February 13, 13

4

GENERAL DESCRIPTION OF MATERIALS CHARACTERIZATION

Generalized forward projector (physics-based)

$$\mathcal{M}_i = \mathcal{P}_i [\underbrace{D(\mathbf{r}), s(\mathbf{r}), \nu(\mathbf{r}), t_{jk}(\mathbf{r}), \dots}_{\text{unknown}} ; \underbrace{T_i(\mathbf{r}, \theta); \tau_i(\mathbf{r}, \theta')}_{\text{can be modeled}} ; \text{noise terms}]$$

Wednesday, February 13, 13

5

EBSD 101

<http://www.ifw-dresden.de/institutes/ikm/organisation/dep-31/methods/electron-back-scatter-diffraction-cbsd>

Wednesday, February 13, 13

6 xi

Complicating factor

- the back-scattered electrons arise from a range of locations and depths inside the sample (stochastic process).

The electrons that escape from the surface undergo interactions with the crystal lattice while they approach the exit surface. These interactions are deterministic, not stochastic

Wednesday, February 13, 13

7

ELECTRON BACK-SCATTER DIFFRACTION

as an example of a forward modeling approach

Diffraction process consists of 3 steps:

- beam-sample interaction
- diffracted beam - scintillator interaction
- scintillator - CCD transfer

Our simulation approach follows this separation by computing ALL possible EBSD patterns first, and then interpolating from this "master pattern" to determine a given pattern on the scintillator.

Ongoing work supported
by ONR-N00014-12-1-0075

xii

Wednesday, February 13, 13

8

ELECTRON BACK-SCATTER DIFFRACTION

For a given scintillator pixel, BSEs originate at a range of depths inside the sample.

Therefore, the signal in single pixel will correspond to an integration over the depth in the sample.

$$\mathcal{P}(\mathbf{k}) = \sum_i \frac{Z_i^2 DW_i}{z_0} \int_0^{z_0} dz |\Psi_{\mathbf{k}}(\mathbf{r}_i)|^2$$

Z_i = atomic number

DW_i = Debye-Waller factor

$\mathbf{r}_i$ = atom coordinates

$\mathbf{k}$ = electron wave vector

Wednesday, February 13, 13

9

ELECTRON BACK-SCATTER DIFFRACTION

Schroedinger equation +

Bloch wave ansatz

$$\Psi(\mathbf{r}) = \sum_j \alpha^{(j)} \sum_{\mathbf{g}} C_{\mathbf{g}}^{(j)} e^{2\pi i(\mathbf{k}^{(j)} + \mathbf{g}) \cdot \mathbf{r}}$$

leads to complex non-symmetric eigenvalue problem

$$\begin{aligned} \mathcal{P}(\mathbf{k}_0) &= \sum_{\mathbf{g}} \sum_{\mathbf{h}} S_{\mathbf{g}\mathbf{h}} L_{\mathbf{g}\mathbf{h}}, \\ S_{\mathbf{g}\mathbf{h}} &\equiv \sum_n \sum_{i \in S_n} Z_n^2 e^{-M_{\mathbf{h}-\mathbf{g}}^{(n)}} e^{2\pi i(\mathbf{h}-\mathbf{g}) \cdot \mathbf{r}_i}, \\ L_{\mathbf{g}\mathbf{h}} &\equiv \sum_j \sum_k C_{\mathbf{g}}^{(j)*} \alpha^{(j)*} \mathcal{I}_{jk} \alpha^{(k)} C_{\mathbf{h}}^{(k)}. \end{aligned}$$

eigenvectors

eigenvalues

$$\begin{aligned} \alpha_{jk} &= q^{(j)} + q^{(k)}; \\ \beta_{jk} &= \gamma^{(j)} - \gamma^{(k)}. \end{aligned}$$

$$\begin{aligned} \mathcal{I}_{jj} &= \frac{1 - e^{-4\pi q^{(j)} z_0}}{4\pi q^{(j)} z_0}; \\ \mathcal{I}_{jk} &= \frac{1 - e^{-2\pi(\alpha_{jk} + i\beta_{jk}) z_0}}{2\pi(\alpha_{jk} + i\beta_{jk}) z_0} \quad (j \neq k); \end{aligned}$$

adjustable parameter

- Each detector pixel corresponds to a different exit beam direction, so first we compute all possible exit beam directions (accounting for crystal and diffraction symmetry), and then we sample this set via interpolation.
- This produces a pattern at the scintillator, which is then further adjusted to account for: orientational modulation of back-scatter yield, scintillator detective quantum efficiency, Poisson electron detection noise, fiber or lens coupling optics, CCD point spread function, and CCD binning mode.

Wednesday, February 13, 13

xiii
10

ELECTRON BACK-SCATTER DIFFRACTION

Sampling process: compute BSE yield for all possible electron wave vectors, which results in numerical values on a (hemi)-sphere.

For efficient storage and easy interpolation, project the hemisphere on a square or hexagonal 2D grid using an equal-area projection.

D. Rosca, *New uniform grids on the sphere*, *Astronomy & Astrophysics*, **520**, A63 (2010)

Wednesday, February 13, 13

11

ELECTRON BACK-SCATTER DIFFRACTION

Uniform equal-area mappings

xiv

Wednesday, February 13, 13

12

Wednesday, February 13, 13

13

Wednesday, February 13, 13

xv
14

ELECTRON BACK-SCATTER DIFFRACTION

Scintillator mapped onto modified Lambert projection.

$$(\varphi_1, \Phi, \varphi_2) = (27^\circ, 75^\circ, 310^\circ)$$

Wednesday, February 13, 13

15

ELECTRON BACK-SCATTER DIFFRACTION

(a)

background intensity profile by averaging experimental patterns

(b)

EBSD pattern with background included

(c)

Poisson noise added

xvi

Wednesday, February 13, 13

16

ELECTRON BACK-SCATTER DIFFRACTION

Experimental, 8x binning

Simulated

Simulation speed: about 10 patterns per second on single 3GHz processor

Problem: background intensity model does not contain any physics ...

Wednesday, February 13, 13

17

ELECTRON BACK-SCATTER DIFFRACTION

- ◆ the real problem: there is no easy way to combine the essentially stochastic nature of electron back-scattering with dynamical elastic scattering theory...

Monte Carlo

Schroedinger Equation

MC can be used to study the depth distribution of BSE events, as well as the energy distribution...

We have implemented a basic MC model to study depth and energy distributions for a specific geometry.

Wednesday, February 13, 13

xvii

18

ELECTRON BACK-SCATTER DIFFRACTION

1 billion incident electrons, 30 kV; 48% reach scintillator

(a)

(b)

(c)

Wednesday, February 13, 13

19

ELECTRON BACK-SCATTER DIFFRACTION

(a)

(b)

These curves can be used as weight factors for dynamical simulations ...

(a)

(b)

xviii

Wednesday, February 13, 13

20

ELECTRON BACK-SCATTER DIFFRACTION

Merging Monte Carlo and dynamical computations:

$$\begin{aligned}\mathcal{P}(\mathbf{k}_0) &= \sum_{\mathbf{g}} \sum_{\mathbf{h}} S_{\mathbf{gh}} L_{\mathbf{gh}}, \\ S_{\mathbf{gh}} &\equiv \sum_n \sum_{i \in S_n} Z_n^2 e^{-M_{\mathbf{h}-\mathbf{g}}^{(n)}} e^{2\pi i(\mathbf{h}-\mathbf{g}) \cdot \mathbf{r}_i}, \\ L_{\mathbf{gh}} &\equiv \sum_j \sum_k C_{\mathbf{g}}^{(j)*} \alpha^{(j)*} \mathcal{I}_{jk} \alpha^{(k)} C_{\mathbf{h}}^{(k)}, \\ \mathcal{I}_{jk} &= \frac{1}{z_0} \int_0^{z_0} e^{-2\pi(\alpha_{jk} + i\beta_{jk})} dz \\ \mathcal{I}_{jk} &= \frac{1}{z_0(E)} \int_0^{z_0(E)} \lambda(E, z) e^{-2\pi(\alpha_{jk} + i\beta_{jk})} dz\end{aligned}$$

from MC

Wednesday, February 13, 13

21

ELECTRON BACK-SCATTER DIFFRACTION

Energy-dependent master EBSD pattern for Ni [15 - 30 keV]

xix

22

EBSD with E-dependence

IN100, Euler angles (146.38°, 19.63°, 172.87°)

Wednesday, February 13, 13

23

What's next?

- ◆ improve realism of MC simulations by using different models for stopping power; currently we use a continuous stopping power model, which is probably not fully realistic, so the actual output of the MC model could change quite a bit in the future ...
- ◆ current energy-weighted dynamical EBSD simulations provide electron count at the scintillator.
- ◆ to get from scintillator to CCD, we need to know the point spread function of the camera
 - ◆ we are currently measuring this function for a number of camera systems
- ◆ include detector noise, both at the scintillator and the CCD stage (Poisson counting statistics), as well as binning, and proper brightness/contrast scaling

XX Wednesday, February 13, 13

24

Conclusions

- ◆ We have successfully merged Monte Carlo simulations with dynamical electron channeling simulations, to obtain a new algorithm for EBSD patterns.
- ◆ Ongoing work will lead to better understanding of EBSD camera systems as well as realistic simulated patterns.
- ◆ A similar approach (physics-based, exploring all steps in the pattern formation process) will need to be applied to all other imaging / diffraction / spectroscopy modalities; several of these are currently ongoing.