

Dynamics and Fluctuations in Biomedical Photonics XIII

Valery V. Tuchin
Kirill V. Larin
Martin J. Leahy
Ruikang K. Wang
Editors

14–15 February 2016
San Francisco, California, United States

Sponsored and Published by
SPIE

Volume 9707

Proceedings of SPIE 1605-7422, V. 9707

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Dynamics and Fluctuations in Biomedical Photonics XIII, edited by Valery V. Tuchin,
Kirill V. Larin, Martin J. Leahy, Ruikang K. Wang, Proc. of SPIE Vol. 9707, 970701
© 2016 SPIE · CCC code: 1605-7422/16/\$18 · doi: 10.1117/12.2229270

The papers 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. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is 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 these proceedings:

Author(s), "Title of Paper," in *Dynamics and Fluctuations in Biomedical Photonics XIII*, edited by Valery V. Tuchin, Kirill V. Larin, Martin J. Leahy, Ruikang K. Wang, Proceedings of SPIE Vol. 9707 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 1605-7422

ISSN: 2410-9045 (electronic)

ISBN: 9781628419412

Published 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

Copyright © 2016, Society of Photo-Optical Instrumentation Engineers.

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 SPIE 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 1605-7422/16/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL
LIBRARY**

SPIDigitalLibrary.org

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of 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 and print versions of the publication. SPIE uses a six-digit CID article numbering system structured as follows:

- 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.

Contents

- vii *Authors*
- ix *Conference Committee*
- xi *Introduction*

SPECKLE TECHNOLOGIES

- 9707 05 **A new sensor for stress measurement based on blood flow fluctuations** [9707-5]
- 9707 06 **Instrument to detect syncope and the onset of shock** [9707-6]

FUNCTIONAL IMAGING

- 9707 0D **Blood flow changes after unilateral carotid artery ligation monitored by optical coherence tomography** [9707-12]
- 9707 0E **Quantitative Mueller matrix microscope: theory, equipment, calibration, and applications (Invited Paper)** [9707-13]

KEYNOTE SESSION

- 9707 0H **Functional monitoring of blood flow dynamics in brain with photon correlation techniques (Invited Paper)** [9707-51]

FUNCTIONAL AND CLINICAL IMAGING I

- 9707 0J **Detection of dermal systemic sclerosis using noncontact optical coherence elastography** [9707-17]
- 9707 0K **Transformation of full 4×4 Mueller matrices: a quantitative technique for biomedical diagnosis** [9707-18]
- 9707 0L **Noncontact imaging of plethysmographic pulsation and spontaneous low-frequency oscillation in skin perfusion with a digital red-green-blue camera** [9707-19]
- 9707 0M **Breath air measurement using wide-band frequency tuning IR laser photo-acoustic spectroscopy** [9707-21]

FUNCTIONAL AND CLINICAL IMAGING II

9707 0N **3D tissue engineered micro-tumors for optical-based therapeutic screening platform**
[9707-22]

TISSUE AND CELL DYNAMICS

9707 0S **Biodynamic profiling of three-dimensional tissue growth techniques (Invited Paper)**
[9707-26]

9707 0V **Measuring intracellular motion in cancer cells using optical coherence tomography**
[9707-29]

9707 0W **DoFP polarimeter based polarization microscope for biomedical applications** [9707-30]

9707 0X **Increasing the penetration depth for ultrafast laser tissue ablation using glycerol based optical clearing** [9707-31]

POSTER SESSION

9707 0Z **Demonstration of brain noise on human EEG signals in perception of bistable images**
[9707-33]

9707 10 **Estimation of degree of synchronization in epileptic brain** [9707-34]

9707 11 **Multilayer structure formation via homophily and homeostasis** [9707-35]

9707 12 **Analysis of the establishment of the global synchronization in complex networks with different topologies of links** [9707-36]

9707 13 **THz-range generation frequency growth in semiconductor superlattice coupled to external high-quality resonator** [9707-37]

9707 14 **Experimental study on synergistic effects of reflectance and transmittance for near infrared spectroscopy** [9707-38]

9707 15 **Monte Carlo simulation study on the availability of the floating-reference theory to diffused transmittance spectra** [9707-39]

9707 17 **A rapid and reversible skull optical clearing method for monitoring cortical blood flow**
[9707-41]

9707 18 **Recognition of short-term changes in physiological signals with the wavelet-based multifractal formalism** [9707-42]

9707 19 **Speech signal denoising with wavelet-transforms and the mean opinion score characterizing the filtering quality** [9707-43]

- 9707 1A **Full-field tracking and measuring of particle motion in capillary vessels by using time-varying laser speckle** [9707-44]
- 9707 1C **OCT as a convenient tool to assess the quality and application of organotypic retinal samples** [9707-46]
- 9707 1D **Measurement of cerebral blood flow rate and its relationship with brain function using optical coherence tomography** [9707-47]
- 9707 1H **Quantitative assessment of reactive hyperemia using laser speckle contrast imaging at multiple wavelengths** [9707-20]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Aizu, Yoshihisa, 0L
Aoki, Yuta, 0L
Bailey, Ryan C., 0N
Baker, Wesley B., 0H
Ben-Yakar, Adela, 0X
Boccaletti, Stefano, 11
Borisov, Alexey V., 0M
Boyko, Andrey A., 0M
Bulanova, Anna A., 0M
Buldú, Javier M., 11
Chang, Jintao, 0E, 0K, 0W
Christian, James F., 06
Dana, Syamal K., 12
Das, Soumen, 0N
Detre, John A., 0H
Dou, Shidan, 1D
Du, Yong, 0J
El Haj, Alicia J., 1C
Elmajdob, Mohamed, 0N
Farkas, Dana, 06
Fenn, Michael B., 0N
Fernandez, Daniel E., 06
Fine, I., 05
Gabay, Ilan, 0X
Gannon, Kimberly, 0H
Gater, Rachel, 1C
Grubov, Vadim V., 0Z
Han, Zhaolong, 0J
Hannon, Timothy S., 0N
He, Chao, 0K, 0W
He, Honghui, 0E, 0K, 0W
Hicks, M. John, 0J
Hoshi, Akira, 0L
Hramov, Alexander E., 0Z, 10, 11, 12, 13, 19
Hsu, Thomas, 0J
Jiang, Jingying, 14, 15
Johnson, Christopher P., 06
Joyner, Michael J., 06
Kaminsky, A. V., 05
Karapuzikov, Alexey A., 0M
Kavuri, Venki, 0H
Kharchenko, Alexander A., 12
Khoshnaw, Nicholas, 1C
Khranova, Marina V., 11, 12, 13
Kistenev, Yury V., 0M
Kolios, Michael C., 0V
Kolodziejski, Noah J., 06
Koronovskii, Alexey A., 0Z, 10, 11, 12
Kostyukova, Nadezhda Y., 0M
Kurovskaya, Maria K., 0Z, 12
Kuzmin, Dmitry A., 0M
Larin, Kirill V., 0J
Li, Jiasong, 0J
Li, Lin, 14, 15
Liang, Chengbo, 0D
Liu, Chih-Hao, 0J
Liu, Jiajia, 14, 15
Liu, Jian, 1D
Lu, Junsheng, 14, 15
Ma, Congcong, 14, 15
Ma, Hui, 0E, 0K, 0W
Ma, Yushu, 0D, 1D
Ma, Zhenhe, 0D, 1D
Makarov, Vladimir V., 11, 12, 13
Maksimenko, Vladimir A., 11, 13
Martin, Chris, 0X
Mason, Eric M., 0N
McAdams, Daniel R., 06
Merrill, Dan, 0S
Mohan, Chandra, 0J
Moskalenko, Olga I., 10, 11, 12
Mullen, Michael T., 0H
Nakano, Kazuya, 0L
Nguyen, Dan, 1C
Niizeki, Kyuichi, 0L
Nishidate, Izumi, 0L
Nolte, David, 0S
Noorani, Shezaan, 0J
Paradis, Norman A., 06
Parthasarathy, Ashwin B., 0H
Pavlov, Alexey N., 0Z, 10, 11, 12, 13, 18, 19
Pavlova, Olga N., 18
Podolsky, Matthew J., 06
Raghunathan, Raksha, 0J
Runnova, Anastasiya E., 0Z
Rybalova, Elena V., 18
Schmitt, Trevor J., 0N
Seal, Sudipta, 0N
Semyachkina-Glushkovskaya, Oxana V., 18
Shenkman, L., 05
Shi, Rui, 17
Sindeev, Sergey S., 18
Sindeeva, Olga A., 18
Singh, Manmohan, 0J
Spano, Joseph L., 0N
Stapels, Christopher J., 06
Subramanian, Kaushik G., 0X
Sun, Hao, 0S

Suo, Yanyan, 0D
Tuchin, Valery V., 0X
Turek, John, 0S
Vishwanath, Karthik, 1H
Wang, Bo, 1A
Wang, Ruikang, 0D
Wang, Ye, 0E
Wang, Yi, 0D, 1A, 1D
Wu, Chen, 0J
Xu, Kexin, 14, 15
Xu, Tao, 0D
Yang, Ying, 1C
Yaseen, Alauldeen S., 19
Ye, Guochang, 0N
Yildirim, Murat, 0X
Yodh, Arjun G., 0H
Young, Anthony, 1H
Zam, Azhar, 0V
Zhang, Chao, 17
Zhang, Luying, 1A
Zhao, Yanjie, 17
Zhao, Yuqian, 0D, 1D
Zhou, Jialin, 0E
Zhu, Dan, 17
Zhuravlev, Maksim O., 10

Conference Committee

Symposium Chairs

James G. Fujimoto, Massachusetts Institute of Technology
(United States)

R. Rox Anderson, Wellman Center for Photomedicine, Massachusetts
General Hospital (United States) and Harvard School of Medicine
(United States)

Program Track Chair

Steven L. Jacques, Oregon Health & Science University
(United States)

Conference Chairs

Valery V. Tuchin, N.G. Chernyshevsky Saratov State University
(Russian Federation) and University of Oulu (Finland)

Kirill V. Larin, University of Houston (United States)

Martin J. Leahy, National University of Ireland, Galway (Ireland)

Ruikang K. Wang, University of Washington (United States)

Conference Program Committee

Pierre O. Bagnaninchi, The University of Edinburgh (United Kingdom)

Wei R. Chen, University of Central Oklahoma (United States)

Joseph P. Culver, Washington University School of Medicine in St.
Louis (United States)

Ekaterina I. Galanzha, University of Arkansas for Medical Sciences
(United States)

Miya Ishihara, National Defense Medical College (Japan)

Jingying Jiang, Tianjin University (China)

Sean J. Kirkpatrick, Michigan Technological University (United States)

Jürgen M. Lademann, Charité Universitätsmedizin Berlin (Germany)

Hong Liu, The University of Oklahoma (United States)

Qingming Luo, Huazhong University of Science and Technology
(China)

Igor V. Meglinski, University of Oulu (Finland)

Brian S. Sorg, National Cancer Institute (United States)

Vladislav Toronov, Ryerson University (Canada)

Lihong V. Wang, Washington University in St. Louis (United States)

Ying Yang, Keele University (United Kingdom)

Anna N. Yaroslavsky, University of Massachusetts Lowell
(United States)

Vladimir P. Zharov, University of Arkansas for Medical Sciences
(United States)

Dan Zhu, Huazhong University of Science and Technology (China)

Session Chairs

- 1 Speckle Technologies
Sean J. Kirkpatrick, Michigan Technological University (United States)
Igor Meglinski, University of Oulu (Finland)
- 2 OCT Plus Speckle Imaging
Martin J. Leahy, National University of Ireland, Galway (Ireland)
- 3 Functional Imaging
Ruikang K. Wang, University of Washington (United States)
Ekaterina I. Galanzha, University of Arkansas for Medical Sciences
(United States)
- 4 Keynote Session
Martin J. Leahy, National University of Ireland, Galway (Ireland)
- 5 Functional and Clinical Imaging I
Kirill V. Larin, University of Houston (United States)
Igor Meglinski, University of Oulu (Finland)
- 6 Functional and Clinical Imaging II
Dan Zhu, Huazhong University of Science and Technology (China)
- 7 Tissue and Cell Dynamics
Valery V. Tuchin, N.G. Chernyshevsky Saratov State University
(Russian Federation) and University of Oulu (Finland)
Anna N. Yaroslavsky, University of Massachusetts Lowell
(United States)

Introduction

This proceedings volume is from the Dynamics and Fluctuations in Biomedical Photonics XIII conference, which was held on February 14 and 15, 2016 at the SPIE Photonics West Conference in San Francisco, California. It was a two-day meeting featuring 32 oral and invited presentations, as well as a joint poster session of 16 poster presentations from leading international research groups. The goal of the conference was to gather essentially different groups of leading researchers, such as biophysicists, medical doctors and physicians, mathematicians, optical and laser engineers, and students, to report the current state of the art. These groups also sought to facilitate future progress in the development of optical and laser technologies based on dynamics and fluctuations approaches (like laser-speckle, speckle-based coherence imaging, microcirculation analysis using various optical techniques and methods, dynamics of molecular diffusion, including nanoparticles, etc.) towards biomedical science and clinical applications. These approaches should be useful for diagnosis and therapy of devastating life-threatening diseases, such as those of the heart, cancer, vascular, mental illness, and many others that manifest as a breach of the living organism's immune systems at the level of molecule, cell, organ, or organism as a whole. We hope the proceedings of this conference will contribute to the development of such interdisciplinary fields of science and applications as dynamics and structures of living systems, biomedical optics and laser medicine, and that it will be useful to scientists, medical doctors, engineers and students.

Prof. Martin J. Leahy chaired a keynote session that had two presentations: an invited paper entitled "Functional monitoring of blood flow dynamics in brain with photon correlation techniques" by Prof. Arjun G. Yodh, et al., Univ. of Pennsylvania, (USA), and a keynote presentation about "Speckle fluctuations to probe dynamics on the macroscopic to microscopic scales" by Prof. David A. Boas, Athinoula A. Martinos Ctr. for Biomedical Imaging (USA). David A. Boas is the 2016 recipient of the SPIE Britton Chance Biomedical Award. SPIE presents this award in recognition of his development, application, and dissemination of near infrared spectroscopy and imaging for breast cancer and brain function, and for his perseverance in developing several innovative microscopic methods to further advance our knowledge of cerebral physiology.

Most of the sessions featured invited presentations. The conference kicked off with the invited lectures: "Laser speckle micro rheology for micro-mechanical mapping of bio-materials" by Zeinab Hajjarian Kashany, et al., Harvard Medical School (USA); "Mapping transverse capillary flow speed using time-varying OCT speckle signals" by Woo June Choi and Ruikang K. Wang, Univ. of Washington (USA); "Quantitative Mueller matrix microscope: theory, equipment, calibration, and applications" by Hui Ma, et al., Tsinghua Univ. (China); "Quantification of volumetric cerebral blood flow using hybrid laser speckle contract and optical

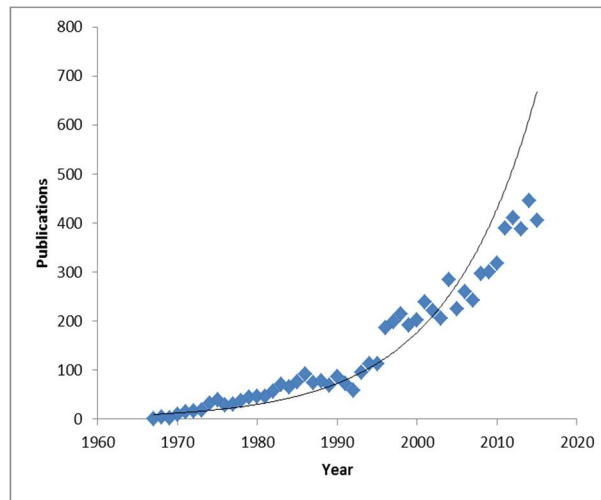
coherence tomography" by Niksa Valim and Andrew K. Dunn, The Univ. of Texas at Austin (USA); "Topical application of nanoparticles: prospects and safety aspects" by Jürgen M. Lademann, et al., Charite Universitätsmedizin Berlin (Germany); and "Biodynamic profiling of three-dimensional tissue growth techniques" by Hao Sun, et al., Purdue Univ. (USA). These presentations drew significant attention from the audience and resulted in large coffee break discussions. These talks provided a nice overview of recent advances in multiple fields of biomedical optics and biophotonics related to dynamic and fluctuation research. The oral sessions and corresponding poster session featured many presentations that described different methods and techniques developed and applied to study complex problems of dynamics and fluctuations in biological systems on the scale ranging from cells to the whole body. The reader is encouraged to browse the table of contents for this issue to learn the full scope of this conference.

The Sunday afternoon panel discussion on Speckle in Biomedical Optics, which was moderated by Profs. Martin J. Leahy, National Univ. of Ireland, Galway (Ireland) and Sean Kirkpatrick, Michigan Technological Univ. (USA), included leading biophotonics researchers who have made seminal contributions to our understanding of speckle in biomedical optics and was seeded by one introductory slide from each panelist to present the latest developments and explore the most exciting future directions in speckle research. The discussion was opened by Martin Leahy (NUI Galway) with a general introduction and overview. The panelists introduced items of topical interest in the modelling, suppression and use of speckle. Sean Kirkpatrick outlined the origins of speckle and some of its uses. This followed excellent lectures from David Boas and Arjun Yodh on the use of speckle with particular emphasis on brain hemodynamics and regulation.

Figure 1.

Publication history of laser speckle.

Source: Scopus 15 March 2016 search for publications with 'laser' and 'speckle'.



Speckle technologies tend to be easy to implement, which turns out to be both an advantage and disadvantage. There are many publications on laser speckle. One key challenge is to develop standards for speckle measurements that yield quantitative, reliable and reproducible results between different laboratories, between different studies, and between different individuals in animal and clinical investigations.

Since the first paper on laser speckle, "Measurement potential of laser speckle velocimetry" by R. J. Adrian in 1966, the number of papers concerning laser speckle published each year has grown to 446 in 2014 (source: Scopus), with more than 7000 published before the end of 2015.

As outlined by Jessica Ramella-Roman, speckle is a sometimes unwanted feature of images generated with coherent light, since it adds noise to the images. Our understanding of speckle generated by laser light interaction with tissue has advanced across a broad range of biophotonics, so this is a good time to gather what has been learned with a view to cross-fertilizing the various applications for which speckle is an important feature. Advances have been made both in the suppression of speckle noise and in the extraction of key information relating to structure (e.g. type of plaque in the coronary artery) and function (microcirculatory blood flow).

Many of the recent papers are based on biophonic applications of speckle. Laser speckle blood perfusion imaging is a well-known¹ technique, sometimes known as LASCA, which makes use of the blurring of speckles from moving blood cells to identify and attempt to quantify flow variations. Its speed advantage over its cousin, laser Doppler, has opened up many additional bio applications of perfusion imaging. For example, Valery Tuchin outlined that full-field laser speckle flowmetry provides a real-time imaging of superficial blood microcirculation which allows one to detect changes in oscillatory dynamics of microvascular perfusion in living organs like kidneys. He showed how elevation of laser power

density affects quality of the recorded signal and improves detectability of temporal changes in microvascular perfusion providing better knowledge of dynamics in the rat kidney.²

Interestingly, it is possible to monitor variations of blood perfusion deep in tissue using diffuse correlation spectroscopy (DCS) as outlined by Arjun Yodh.³ This very important development goes some way to overcome the limitation to superficial tissues, although there is a loss of spatial resolution. Fast DCS will open up new avenues for discovery of physiological phenomena using modulation amplitude, phase-difference between flow and pressure, distribution of flow oscillations, and particularly dynamics and autoregulation in the brain. Igor Meglinski discussed how Monte Carlo simulation can be used to better understand the dynamic diffusion correlation to measure flow.

A growing number of papers have investigated dynamic speckle signals in optical coherence tomography (OCT), and they have been applied to imaging for microvascular architecture in 3D, which has better resolution than diffuse methods and greater depth than the confocal microscopy. Doppler, phase shift, speckle variance, OMAG, and cmOCT are all benefits of this dynamic speckle to contrast functional vasculature.^{4,5} David Sampson⁶ reported on the use of speckle in optical coherence elastography for differentiation of tissue types and on the five-fold improvement in resolution provided by optical coherence tomography (OCM). Kirill Larin illustrated improvements using 3D speckle variance and anomaly detection with exquisite images of a mouse embryo yolk sack.⁷ It was also shown how sub-resolution speckle variations could be used, like to map cilia beating in reproductive tracts.⁸ Kishan Dholakia illustrated how the deterministic properties of laser speckle interaction with scattering media can be used to stabilize a laser to a 24 kHz dither by sub-femtometer measurement of the laser wavelength.⁹

The conference chairs would like to thank the members of the Technical Program Committee for their help in organizing the conference. We sincerely appreciate the support of SPIE and the conference staff. Finally, we would like to thank all of the conference attendees and manuscript authors for their contributions and participation, especially invited and keynote speakers, who helped to make this meeting a success.

Valery V. Tuchin
Kirill V. Larin
Martin J. Leahy
Ruikang K. Wang

REFERENCES

- [1] Boas, D. A. and Dunn, A. K. "Laser speckle contrast imaging in biomedical optics," *J. Biomed. Opt.* **15** (1), 011109 (2010).
- [2] Postnov, D. D., Sosnovtseva, O., and Tuchin, V. V. "Improved detectability of microcirculatory dynamics by laser speckle flowmetry," *J. Biophotonics* **8**(10), 790-794 (2015).
- [3] Durduran, T. and Yodh, A.G. "Diffuse correlation spectroscopy for non-invasive, micro-vascular cerebral blood flow measurement," *Neuroimage* **85**, 51-63 (2014).
- [4] Daly, S. M., and Leahy M. J. "'Go with the flow': a review of methods and advancements in blood flow imaging," *J. Biophotonics* **6** (3), 217-255 (2013).
- [5] Zhang, A., Zhang, Q.Q., Chen, C.-L., and Wang R.K. "Methods and algorithms for optical coherence tomography based angiography: A review and comparison," *J. Biomed. Opt.* **20**(10), 100901 (2015).
- [6] Curatolo, A. Villiger, M. Lorensen, D. Wijesinghe, P. Fritz, A. Kennedy, B. F. and Sampson, D. D. "[Ultrahigh-resolution optical coherence elastography](#)," *Opt. Lett.* **41**(1), 21-24 (2016)
- [7] Kulkarni, P. M., Rey-Villamizar, N., Merouane, A., Sudheendran, N., Wang, S., Garcia, M., Larina, I. V., Roysam, B. and Larin, K. V. "Algorithms for improved 3-D reconstruction of live mammalian embryo vasculature from optical coherence tomography data," *Quantitat. Imag. Med. Surg.* **5** (1), 125-135 (2015).
- [8] Wang, S., Burton J. C., Behringer, R. R., and Larina, I. V. "In vivo micro-scale tomography of ciliary behavior in the mammalian oviduct," *Sci. Rep.* **5**, 13216 (2015).
- [9] Metzger, N., Dholakia, K., and Mazilu, M. "Wavelength detection with sub femtometer resolution," *SPIE Proc.* 9707 (2016).

