Special Section Guest Editorial: Hard X-Ray Tomography with Micrometer Resolution

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Last year, we celebrated the 125th anniversary of medical imaging based on Röntgen's discovery.[1] One of the first radiographs was his wife's hand with a metallic ring that has been replicated numerous times. These early radiographs showed impressive details of bone structures. Thanks to tomographic imaging, introduced five decades ago[2] and extended to the micrometer scale four decades ago,[3] trabecular bone can now be visualized three-dimensionally with isotropic, submicrometer resolution. This special section of the *Journal of Medical Imaging* (JMI) marks this anniversary with a collection of eight contributions, mainly based on the SPIE Conference "Developments in X-ray Tomography XIII" which occurred in San Diego, California, August 2–3, 2021, with both physical and remote participation.[4] Despite the inconvenience caused by traveling restrictions, the traditional exchange of ideas and brainstorming was continued via on-site discussion, on-line presentation, and off-line Slack communication. The submission of more than 50 contributions demonstrated the momentum of the advancement in research, development, and applications. The success of this conference series inspired us to organize this special section as a snapshot, albeit limited, of this important niche area featured by hard x-ray tomography at the micrometer level.

The article by S. Alloo et al. is on dark-field tomography through intrinsic x-ray speckle-tracking (https://doi.org/10.1117/1.JMI.9.3.031502). The Fokker-Planck formalism is used to model the deformation of illuminating reference beam speckles under moderate assumptions and inverted using a weighted determinants approach with encouraging results. While classic pathology takes days to analyze surgical biopsies in three dimensions, W. Twengström et al. developed laboratory x-ray propagation-based phase-contrast imaging system to assess intra-operative three-dimensional tumor resection margins (https://doi.org/10.1117/1.JMI.9.3.031503). The system uses a liquid-metal jet microfocus source and a scintillator-coated CMOS detector and reconstructs tumors with sharp edges in cellular resolution and histological landmarks. R. Power et al. used propagation-based phase-contrast synchrotron radiation for micro computed tomography to non-destructively examine both modern and archeological samples of dental calculus (https://doi.org/10.1117/1.JMI.9.3.031505). These authors identified important features of deposits formed on the outside of the tooth, including previously undetected negative imprints of enamel and dentin growth markers, the noncontiguous structure of calculus layers with multiple voids, and entrapped plant remains. F. Schaff et al. studied spectral propagation-based x-ray phase-contrast computed tomography for material-specific imaging (https://doi.org/10.1117/1.JMI.9.3.031506). They demonstrated phase-retrieval from spectral propagation-based CT data of a two-component sample and a multi-material capacitor sample, based on the Alvarez–Macovski model. Their phase-retrieval results demonstrate the feasibility and potential of this technology.

In addition to the above four phase-contrast and dark-field imaging articles, the algorithm study contributed by M. Grewar et al. combines the minimum least-squares and maximum-likelihood criteria for computed tomography reconstruction (https://doi.org/10.1117/1.JMI.9.3.031508). Specifically, they quadratically expanded loglikelihood and demonstrated that this modification can be efficiently implemented to maximize likelihood under Poisson–Gaussian models widely used in practice. On the application side, S.R. Stock et al. used energy dispersive diffraction tomography to map a blue shark centrum with its double cone structure and intermedialia (https://doi.org/10.1117/1.JMI.9.3.031504). They found that the bioapatite in the cone walls and wedges is oriented to resist lateral and axial deflections, respectively. Based on an awarded conference paper,[5] the article lead-authored by A. Migga systematically compared the performance of three cutting-edge laboratory systems for three specimens namely, paraffin-embedded zebrafish larva, bare archaeological human tooth, and paraffin-embedded porcine nerve (https://doi.org/10.1117/1.JMI.9.3.031507). These systems include SkyScan 2214 (Bruker-microCT, Kontich, Belgium), Exciscope prototype (Stockholm, Sweden), and Xradia 620 Versa (Zeiss, Oberkochen, Germany). The obtained datasets were registered to the benchmark synchrotron radiation-based tomography from the same specimens to show relative strengths and weaknesses of these systems. The article lead-authored by R. Ammann is on the three-dimensional analysis of the aligner gaps and thickness distributions of thermoformed cellulose-coated foils of polyethylene terephthalate glycol-modified, using hard x-ray microtomography (https://doi.org/10.1117/1.JMI.9.3.031509). This topic is important because bruxism generates microplastics detected in patient's blood, in case of using non-coated aligners for orthodontic treatment. The automatic morphological assessment of the microtomography data was validated by manual inspection. The cover image of the present JMI issue (Volume 9 Issue 3) displays the detected gaps between teeth and aligners as well as the thickness distribution of the aligner foil. Note that the red color represents the thickest part of the aligner foil on the occlusal surface, exactly where the abrasion is taking place.

We are proud to publish in this JMI special section selected advances in microtomography instrumentation and algorithm developments for reconstruction and evaluation of a variety of objects. Today, x-ray tomographic imaging employs not only conventional attenuation contrast, but often phase contrast and x-ray scattering to provide complementary information. We remain confident that higher spatial resolution, complementary contrast mechanisms, evolving and emerging CT applications down to nanometer resolution will play increasing roles in the years to come. Since the pandemic seems basically under control, we anticipate that the upcoming conference "Developments in X-ray Tomography XIV" with more than 60 accepted contributions will be physically held in San Diego, August 21-25, 2022. Look forward to these presentations, interactions, and related SPIE journal articles.

Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.

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Bert Müller holds the Thomas Straumann Chair for materials science in medicine at the University of Basel, Switzerland, and is a founding director of the Biomaterials Science Center. He received his MS degree in physics from Dresden University of Technology, Germany, his PhD in experimental physics from the University of Hannover, Germany, and his habilitation degree in experimental physics from ETH Zurich, Switzerland. His current research interests include high-resolution hard x-ray imaging and physics-based approaches in medicine and dentistry. He is a fellow of SPIE and named as the 2022 recipient of the SPIE Biophotonics Technology Innovator Award. He has been chairing the SPIE "Developments in X-ray Tomography" conference series since 2016, after Stuart R. Stock and the pioneer Ulrich Bonse.

Stuart R. Stock is a research professor at the Feinberg Medical School and at the Simpson-Querrey Institute, Northwestern University, Chicago. Before that, he was a professor of materials science and engineering at Georgia Tech. He has been publishing in the field of x-ray micro-computed tomography since 1985 when his first paper appeared in SPIE proceedings. He is a fellow of SPIE and has chaired the SPIE conference "Developments in X-ray Tomography VI-X" for several years. He is the author of the book *MicroComputed Tomography – Methodology and Applications* (1st Ed., 2008, and 2nd Ed., 2019).

Ge Wang is a Clark & Crossan Chair Professor and director of Biomedical Imaging Center, Rensselaer Polytechnic Institute, Troy, New York, United States. He pioneered the spiral/helical cone-beam/multislice method in the early 1990s and wrote many follow-up papers in this area. There are ~200 million medical CT scans yearly, a majority of which are performed in the spiral cone-beam mode. He published the first perspective on AI-empowered tomographic imaging in 2016, and a series of papers on diverse deep learning-based imaging topics. He wrote 550+ journal articles in *PNAS*, *Nature*, *Nature Machine Intelligence*, *Nature Communications*, and other well-known journals. He has given many seminars, keynotes, and plenaries, including two National Institutes of Health (NIH) AI Imaging presentations (2018) and a plenary talk at SPIE O+P (2021). He chairs the SPIE "Developments in X-ray Tomography" conference series. He is a fellow of IEEE, SPIE, AAPM, OSA, AIMBE, AAAS, and the National Academy of Inventors (NAI). He has received various awards, including the IEEE EMBS Academic Career Achievement Award (2021), the IEEE R1 Outstanding Teaching Award (2021), the SPIE Aden & Marjorie Meinel Technology Achievement Award (2022), and the Sigma Xi Walston Chubb Award for Innovation (2022).

Jovan G. Brankov, PhD, is a professor in the ECE/BME Department at Illinois Tech. His current research interests include domain-aware deep-learning anthropomorphic models for task-based image quality assessment, phase-contrast x-ray mammography and radiography, optical fluorescence imaging of surgical margins, and 4D and 5D tomographic image reconstruction methods for medical image sequences. He established the Advanced X-ray Imaging Laboratory (AXIL) at Illinois Tech, which is currently developing a phase-contrast x-ray device. He is currently serving as an associate editor for *IEEE Transactions on Biomedical Engineering*, *Medical Physics* (AAPM), and *Journal of Medical Imaging* (SPIE); program committee member for SPIE Image Perception conferences; and reviewer on the NIH SBIB (10) panel.