Guest Editorial: Introduction to the Special Section on Computational Photography

Yoav Y. Schechner, Kavita Bala, Ori Katz, Kalyan Sunkavalli, and Ko Nishino

1 Introduction

The past year has been significant in many ways. For the scientific community of computational photography, we have a hybrid in-person conference, one of the first in the vision/optics/graphics community post-pandemic. Further, we expanded our community to better include the physical optics community. This move was made consciously to strengthen and expand the span of computational photography and make these different, yet closely related communities, have a common venue to share ideas. This expansion we believe has significantly enriched the papers submitted to this special issue, through the IEEE International Conference on Computational Photography (ICCP'2021). Moreover, this year, the paper review, decision and revision process includes additional elements to enhance the quality of the publications.

2 Research in the Covid-19 Period

Like all society, the Covid-19 pandemic significantly impacted academic scholarship, including the ability of people to submit papers. The situation wrought by the pandemic this year was worse than that leading to submissions to ICCP'2020 and its associated TPAMI special issue. To accommodate the unique circumstances of our time, we welcomed papers that had not necessarily been able to do experimental validation as is typical in our field. Despite this, a significant number of submitted papers included serious experiments, as seen in the papers of this TPAMI Special Section, described below. Moreover, all papers in this Special Section have been presented, among other papers, in ICCP, held on May 23-25, 2021. We were able to organize a hybrid event for the conference: one day (May 23) is in-person for local participants in Israel, as traditional conferences have been prior to the Covid period. Currently international travel restrictions make it unlikely for people who do not reside in Israel to participate in-person. The two following days are in a virtual-conference mode. This format increases the exposure to the works, while enabling networking to the best extent possible.

3 Inclusion of Physics/Optics

The area of computational photography is at the intersection of imaging, sensors, signal processing, computer vision and graphics. Since 2009, it has been the mission and vision of ICCP to bring into the fold researchers from these communities. Specifically, the involvement of physical-optics researchers is critical to the success of our community. However, in practice, the involvement of the physical-optics community has been limited, despite the shared interests and, often, similarity of problems and methods. In the publication culture of physics, conferences are used for presenting work which is not peer-reviewed. This is contrary to ICCP culture that has hitherto only allowed peer-reviewed papers to be judged and orally presented. We believe this cultural discrepancy hindered the core cause of ICCP. Consequently, this narrowed the base of papers that could have been submitted to this Special Section.

This year we have dramatically increased the involvement of researchers from the physics and optics community through the review process, ICCP organization and exposure at presentations. Leaders from the physical optics community contributed to the high level of quality of papers, reviews, and presentations. To achieve this integration, a Physics/Optics Board was formed in ICCP. Leaders in this field felt comfortable submitting and orally presenting abstracts, by the customs of the physics community. These presentations were done shoulder to shoulder with vision and graphics researchers who chose to submit full-length papers for peer review. Indirectly, this inclusion helped increase the quality and competitiveness of submitted papers. This enabled us to select for this Special Section papers of higher quality.

4 Paper Review and Selection

One of the important priorities of the review process was to ensure a high quality program. We describe the process we followed to achieve this goal:

1. All members of the program committee (PC) were carefully and individually selected and invited by the ICCP program chairs (Kavita Bala, Ori Katz, Yoav Schechner). We aimed to get highly experienced,

- *Yoav Y. Schechner is with the Viterbi Faculty of Electrical Engineering, Technion - Israel Institute of Technology, Haifa 3200003, Israel. E-mail: yoav@ee.technion.ac.il.*
- *Kavita Bala is with the Department of Computer Science, Ann S. Bowers College of Computing and Information Science, Cornell University, Ithaca, NY 14850 USA. E-mail: kavitabala@cornell.edu.*
- *Ori Katz is with the Department of Applied Physics, Faculty of Science, Hebrew University of Jerusalem, Jerusalem 91904, Israel. E-mail: orik@mail.huji.ac.il.*
- *Kalyan Sunkavalli is with the Adobe Research, San Jose, CA 95110-2704 USA. E-mail: sunkaval@adobe.com.*
- *Ko Nishino is with the Department of Intelligence Science and Technology, Kyoto University, Kyoto 606-8501, Japan. E-mail: nishino.ko.5a@kyoto-u.ac.jp.*

Digital Object Identifier no. 10.1109/TPAMI.2021.3078707

senior researchers with extensive experience from past years in ICCP as well as other leading venues of vision, graphics and optics, and a few accomplished junior PC members with strong research in these areas.

2. The call for papers and the reviewer guidance explicitly prioritised novelty of ideas over perfected increments.
3. Papers and reviews followed the anonymous double-blind protocol, as is common in major computer vision conferences. Conflicts of interest were declared by all authors and PC members. Avoidance of conflicts between authors and PC members was then overseen both by the submission and review system (Conference Management Toolkit, CMT3) and personal knowledge of the Program Chairs. The Program Chairs did not submit papers. Program Chairs who had a conflict of interest with a paper, were not involved in reviews and decisions regarding the paper.
4. This year, ICCP ran The Toronto Paper Matching System (TPMS) to rank relevance of each paper to each PC member.
5. All PC members posted bids to review particular papers. This helped us obtain reviewers that are experts, dedicated and highly motivated to study each paper. Indeed, 100 percent of the requested reviews were carried out.
6. Each paper was allocated at least four expert reviewers from the PC. For each paper, at least one reviewer had been a PC member in past ICCPs; most papers had several reviewers of ICCP experience.
7. For each paper, the reviewers explicitly reported if a paper is suitable for the IEEE TPAMI Special Section.
8. After the reviews were released to the authors, they could submit a rebuttal. The rebuttal spanned up to two pages per paper giving the authors plenty of space to respond. Moreover, we allowed rebuttals to include additional results and experiments, if these addressed the reviewer concerns. Most authors submitted rebuttals. For each paper, the rebuttals and reviews were jointly discussed by the PC members and Chairs. At the end of this discussion, PC members revisited the ranking of the paper they had reviewed and submitted final conclusions regarding acceptance and suitability for the IEEE TPAMI Special Section.
9. Based on this information, the Program Chairs reached decisions. Out of 52 valid submissions, seven papers became candidates to appear in this Special Section of IEEE TPAMI. Twenty eight papers were either rejected or withdrawn. The rest were either accepted, or conditionally accepted to the Proceedings of ICCP'2021. Several weeks later, the latter were finally accepted to the Proceedings of ICCP'2021, after performing revisions to meet the requirements of the PC.
10. The Special Section is overseen by IEEE TPAMI Associate Editors Kalyan Sunkavalli and Ko Nishino, while the ICCP program chairs are guest editors of this Special Section. A candidate paper that is co-authored by Ko Nishino was handled separately, to avoid conflict of interest: for decisions on this paper, IEEE Editor Sven Dickinson worked with Kalyan Sunkavalli and the guest editors.
11. A revised version was submitted for each candidate paper, together with a detailed summary of changes document, detailing how and where each requirement of the PC was met, and where each claim of the rebuttal was expressed. For each paper, these changes were verified by two PC members who had been original reviewers of the paper, and by the Editors. In several cases, additional rounds of minor revisions and verification followed. When all requirements were met, the candidate papers were accepted to this Special Section of IEEE TPAMI.

We note that a process similar to step 11 also applied to papers that were accepted to the Proceedings of ICCP: they too provided detailed summary of changes. Also in these cases, the Program Chairs and PC members verified that indeed each requirement of the PC was met, and each claim of the rebuttal is incorporated, sometimes after additional rounds of communications. With this background of review and publication rigor, we note that the papers that made it to TPAMI were papers the PC and Editors found as the best among the best.

5 Papers in This Special Issue

We now briefly describe all the papers in this special issue.

5.1 Micro and Macro Imaging

Observing the list of papers that program committee nominated for this special issue, it is remarkable to note that microscopy and macro imaging is a major theme. Moreover, several papers rely on dual-wavelength illumination.

The paper "Learning Optimal Wavefront Shaping for Multi-Channel Imaging" explores an approach to improve 3D localization microscopy. The microscopic scene is sparse. It is simultaneously acquired by two images, using two corresponding point spread functions (PSFs). The two PSFs are jointly optimized for the task, using end-to-end learning. They are implemented in the optical system by splitting the detected light to two paths. The authors show that this allows superior lateral and axial resolutions single-shot reconstruction and improved fluorophore densities, compared to state of the art engineered PSFs. Such multi-PSF designs may prove useful outside the realm of computational microscopy, for example, in design of coded aperture pairs for stereo imaging.

Dual wavelength illumination is used in the paper "Exploiting Wavelength Diversity for High Resolution Time-of-Flight 3D Imaging" for wide-field depth-sensing with sub-millimeter depth resolution, without the need for scanning. The authors achieve this feat by multi-wavelength interferometry, known also as 'superheterodyning', where a sufficiently low frequency beat-note is created by mixing two waves of similar frequencies, and detected by conventional detection electronics. With this approach, the authors are able to both reject the subjective speckle patterns, and reconstruct scenes with a depth resolution given by the synthetic wavelength of the beat frequency. The paper experimentally demonstrates the technique with three different sensor technologies: from a high-end lock-in (time-of-flight) camera to a low-cost CMOS.

Microscopic time of flight is also a main principle in the paper "High Resolution, Deep Imaging Using Confocal Time-of-flight Diffuse Optical Tomography". The main problem in deep-tissue imaging is loss of 3D spatial resolution due to scattering. This problem can be partly mitigated by incorporating time of flight into the approach of diffuse optical tomography. However, computational post-processing of the data is prohibitively expensive. To significantly simplify analysis and reconstruction, the authors propose confocal optical settings and an associated approximation of image-formation based on convolutions. Moreover, as the paper points out, scattering imposes short-range sensitivity of any detector to any source. This is exploited to operate multiple sources simultaneously (multiplexing), instead of sequentially. This, in turn, significantly shortens the acquisition time. The paper thus addresses several key problems that have hindered high resolution, deep tissue imaging. The work includes an extensive set of experiments using a broad range of technologies. These include the use of E-ink display to create absorbing targets, 3D printing of heterogeneous phantoms, and patterning of fluorescent features.

The paper "Non-Rigid Shape from Water" deals with submerged macro (close range) observation of underwater dynamic objects. It yields a a consistent dense 3D shape of dynamic, non-rigid objects by integrating single-frame reconstructions. Light crosses multiple media from the source to the object and back to the camera sensors: water, glass and air. The properties of water pose not just a challenge but also part of the solution. Water has significant absorption in the near-infrared (NIR). This effect is exploited in the paper. The water transmissivity depends both on the distance and the wavelength. Dual-wavelength NIR sensing provides a cue to the distance, in addition to geometric and 3D scene flow cues. The set of unknowns include the object of interest, water turbidity characteristics, and parameters of the source, detectors and glass interface. These unknowns are solved for using a set of optimization problems that are based on comprehensive models. Remarkably, the laboratory experiments span off outdoor field activities, as natural waters were brought from a lake, a river and the ocean.

5.2 Spectral Imaging

The paper "SASSI — Super-Pixelated Adaptive Spatio-Spectral Imaging" achieves video-rate hyperspectral images at very high spectral, temporal and spatial resolutions using scene-adaptive sampling of a hyperspectral scene. Plenoptic imaging traditionally has made a tradeoff between spatial resolution and other dimensions of the plenoptic function; for example, sampling angular resolution at the expense of spatial resolution. This paper instead introduces a design template for plenoptic imaging that avoids that tradeoff by being scene adaptive. They exploit the similarity in spectra between nearby pixels to sub-sample spatially while preserving quality. The paper forms super-pixels of nearby pixels that have similar spectra (using a RGB guide image), and then sparsely samples these super-pixels using a spatio-spectral sampler. The spatio-spectral sampler is identical to that of the single disperser coded aperture snapshot spectral imager (CASSI) architecture with an exception of programmable spatial mask via a spatial light modulator (SLM). This super-pixel based scene-adapative sampling achieves a very high frame rate spatially, temporally and spectrally.

5.3 Seeing Through Display

The paper "Designing Display Pixel Layouts for Under-Panel Cameras" suggests a new way to combine coaxial cameras and display in a flat form. Here, cameras are placed below a display panel, which is an emerging topic in computational image reconstruction. An under-pixel camera is attractive, as it provides a more natural eye-contact in video-conferencing, and enables better fill-factor of the display area. Most previous works focused on optimized algorithms for reconstruction through conventional display designs. Here, the authors computationally search for a new display pixel transmission mask and pixel tiling that would maximize image quality via Wiener deconvolution. They conclude that randomizing the orientation of each display pixel, while keeping the regular grid provides improved results over the conventional design, in both Wiener deconvolution and a CNN-based reconstruction. This is demonstrated by real experiments. This work opens interesting directions to joint design of display pixel layouts and reconstruction algorithms.

5.4 Neural Transient Fields

Neural radiance fields (NeRF) have recently been introduced for estimating radiance fields using neural networks. The paper "Non-line-of-sight Imaging via Neural Transient Fields" adapts this concept for reconstructing non-line-of-sight (NLoS) scenes, based on time-of-flight data of pulsed laser illumination. NLoS imaging from LiDAR-like measurements of light reflected off diffuse walls is a topic under intense research. Conventionally, time-resolved measurements made by ultrafast detectors have led to 3D spatial reconstruction via back-projection or other algebraic approaches. The authors, however, adapt NeRF rendering to reconstruct the 3D scenes, demonstrating competitiveness with the state of the art, and at some occasions yielding better details of hidden 3D shape.

Yoav Y. Schechner received the BA degree in physics, the MSc degree in physics, and the PhD degree in EE from Technion - Israel Institute of Technology, in 1990, 1994, and 2000, respectively. He was a research scientist with Columbia University. Since 2002, he has been a faculty member at the Technion's Viterbi Faculty of Electrical Engineering. He is currently the Diane and Mark Seiden chair in Science. He is also a principal investigator and coordinator of the CloudCT project, funded by ERC. In 2010 and 2011, he was a visiting scientist with Caltech and NASA's Jet Propulsion Laboratory. His research interests include outdoor phenomena and all aspects of imaging. He is currently a program chair of ICCP'2021. He was the recipient of the Technion Distinguished Lecturer Award in 2020, the Best Student Paper Award at CVPR in 2017, the best paper awards at ICCP in 2013 and 2018, the Ray and Miriam Klein Research Award, the Henry Taub Prize for Academic Excellence, the Otto Schwarz Foundation Excellence Award, and the Landau Fellowship.

Kavita Bala received the BTech degree from the Indian Institute of Technology Bombay, and the SM and PhD degrees from the Massachusetts Institute of Technology. She is currently the dean at the Cornell Ann S. Bowers College of Computing and Information Science, Cornell University. She co-founded GrokStyle, a visual recognition AI company, which drew IKEA as a client, and was acquired by Facebook in 2019. She has coauthored the graduate-level textbook Advanced Global Illumination (A K Peters publisher, second edition). Her research interests include computer vision, computer graphics, recognition and visual search, material modeling and acquisition, physically based rendering, and material perception. She was an ACM Fellow in 2019 and was inducted into the SIGGRAPH Academy in 2020. She was the recipient of the SIGGRAPH Computer Graphics Achievement Award in 2020) and the IIT Bombay Distinguished Alumnus Award in 2021. She was with SIGGRAPH's Papers Advisory Group (PAG). She was the editor-in-chief of *Transactions on Graphics*. She chaired SIGGRAPH Asia 2011, and co-chaired Pacific Graphics in 2010 and the Eurographics Symposium on Rendering in 2005.

Ori Katz received the BSc degree in physics and mathematics and the MSc degree in applied mathematics from The Hebrew University of Jerusalem, Israel, in 1999 and 2005, respectively, and the PhD degree in physics from The Weizmann Institute of Science, Israel, in 2011. His professional track includes six years of R&D and team leading outside academia. He is currently an associate professor with the Department of Applied Physics, Hebrew University of Jerusalem, where he leads the Advanced Imaging Lab. He studies new possibilities for imaging and sensing in complex scattering media, enabled by combining optics, acoustics, and advanced computational reconstruction. His works allow deeper and higher resolution imaging in complex media, such as biological tissues, and new possibilities for imaging and sensing with scattered light, such as non-line-of-sight imaging around corners. He is currently a program chair for ICCP'2021. He was the recipient of several prestigious awards and research grants, including the Wolf Foundation Krill Prize in 2019, The Azrieli Faculty Fellowship in 2015, The John F. Kennedy Award for Outstanding Doctoral Thesis in 2011, an ERC Starting Grant in 2015, and an ERC Consolidator Grant 2020.

Kalyan Sunkavalli received the BTech degree from the Indian Institute of Technology Delhi, the MS degree in 2006 from Columbia University, and the PhD degree from Harvard University in 2012. He is currently a senior research scientist at Adobe Research. His research interests include the intersection of computer vision, graphics, computational photography, and machine learning, and focus on understanding, reconstructing, and editing visual appearance from images and videos. He was a program chair for ICCP 2020.

Ko Nishino received the BE and ME degrees in information and communication engineering from from the University of Tokyo, in 1997 and 1999, respectively, and the PhD degree in computer science from the University of Tokyo in 2002. He is currently a professor at the Department of Intelligence Science and Technology, Kyoto University. Before joining Kyoto University in 2018, he was a professor with the Department of Computer Science, Drexel University. His research interests include computer vision and machine learning, including appearance modeling and material recognition, human behavior analysis, and computational photography. He was the recipient of the NSF CAREER Award in 2008.