electronic IMAGING 2021

IS&T International Symposium on Electronic Imaging Science and Technology

11–28 January 2021 • Online

PROCEEDINGS

Imaging Sensors and Systems 2021

Editors: **Jon S. McElvain**, Dolby Labs., Inc. (United States),
Arnaud Peizerat, Commissariat à l'Énergie Atomique (France),
Nitin Sampat, Edmund Optics (United States),
Ralf Widenhorn, Portland State Univ. (United States)

These papers represent the program of Electronic Imaging 2021, held online 11–28 January 2021.

Imaging Sensors and Systems 2021

Conference overview

The Imaging Sensors and Systems Conference (ISS) began with EI 2020, from the merger of the Image Sensors and Imaging Systems Conference and the Photography, Mobile, and Immersive Imaging Conference. Through these conferences, ISS traces its roots to the earlier Digital Photography Conference, which ran for thirteen years.

ISS focuses on image sensing for consumer, industrial, medical, and scientific applications, as well as embedded image processing, and pipeline tuning for these camera systems. This conference will serve to bring together researchers, scientists, and engineers working in these fields, and provides the opportunity for quick publication of their work. Topics can include, but are not limited to, research and applications in image sensors and detectors, camera/sensor characterization, ISP pipelines and tuning, image artifact correction and removal, image reconstruction, color calibration, image enhancement, HDR imaging, light-field imaging, multi-frame processing, computational photography, 3D imaging, 360/cinematic VR cameras, camera image quality evaluation and metrics, novel imaging applications, imaging system design, and deep learning applications in imaging.

Award

Arnaud Darmont Memorial Best Paper Award*

*The Arnaud Darmont Memorial Best Paper Award is given in recognition of IMSE Conference Chair Arnaud Darmont who passed away unexpectedly in September 2018.

Arnaud dedicated his professional life to the computer vision industry. After completing his degree in electronic engineering from the University of Liège in Belgium (2002) he launched his career in the field of CMOS image sensors and high dynamic range imaging, founding APHESA in 2008. He was fiercely dedicated to disseminating knowledge about sensors, computer vision, and custom electronics design of imaging devices as witnessed by his years of teaching courses at the Electronic Imaging Symposium and Photonics West Conference, as well as his authorship of several publications. At the time of his death, Arnaud was in the final stages of revising the second edition of "High Dynamic Range Imaging – Sensors and Architectures", first published in 2013. An active member of the EMVA 1288 standardization group, he was also the standards manager for the organization where he oversaw the development of EMVA standards and fostered cooperation with other imaging associations worldwide on the development and the dissemination of vision standards. His dedication, knowledge, and boundless energy will be missed by the IS&T and Electronic Imaging communities.

Conference Chairs: Jon S. McElvain, Dolby Laboratories, Inc. (United States); **Arnaud Peizerat,** Commissariat à l'Énergie Atomique (France); **Nitin Sampat,** Edmund Optics (United States); and **Ralf Widenhorn,** Portland State University (United States)

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Imaging Sensors and Systems 2021

TUESDAY 19 JANUARY 2021

PLENARY: DEEP INTERNAL LEARNING—DEEP LEARNING WITH ZERO EXAMPLES
Session Chair: Charles Bouman, Purdue University (United States)
10:00 – 11:10

Deep internal learning—Deep learning with zero examples
Michal Irani, *professor, Department of Computer Science and Applied Mathematics, Weizmann Institute of Science (Israel)*

Michal Irani is a professor at the Weizmann Institute of Science. Her research interests include computer vision, AI, and deep learning. Irani's prizes and honors include the Maria Petrou Prize (2016), the Helmholtz "Test of Time Award" (2017), the Landau Prize in AI (2019), and the Rothschild Prize in Mathematics and Computer Science (2020). She also received the ECCV Best Paper Awards (2000 and 2002), and the Marr Prize Honorable Mention (2001 and 2005).

KEYNOTE: SENSOR DESIGN I
Moderator: Jon McElvain, Dolby Laboratories (United States)
Session Chair: Arnaud Peizerat, CEA (France)
11:40 – 13:00

11:40   ISS-089
KEYNOTE: Deep-trench isolation: The holy grail for image sensors?, *Albert Theuwissen[1,2]; [1]Harvest Imaging (Belgium) and [2]TU Delft (the Netherlands)*

Keynote speaker Albert Theuwissen received a degree in electrical engineering and his PhD from the Catholic University of Leuven (Belgium, 1977 and 1983, respectively). In 1983 he joined Philips Research Labs (the Netherlands) and in 2002 he started working for DALSA. His whole career he was involved in R&D of solia-state image sensors. He issued several patents and he is author or cc-author of more than 240 technical papers, including a textbook "Solia-State Imaging with Charge-Coupled Devices". He acted as general chairman of the International Image Sensor Workshop in '97, '03, '09, and '15, and as International Technical Program Chair of the ISSCC2010. In 2001, he became par-time professor at the Delft University of Technology, the Netherlands. He left DALSA in 2007, and founded Harvest Imaging. Since then he is fully focusing on training, teaching, and consulting in the field of solia-state imaging technology. In 2011 he received the Electronic Imaging of the Year Award and in 2017 he was elected as president of the International Image Sensor Society.

12:20
Roundtable with Albert Theuwissen

12:40   ISS-090
A 64M CMOS image sensor using 0.7μm pixel with high FWC and switchable conversion gain (Invited), *Jay Jung, Omnivision Technologies, Inc. (United States)*

Since 2016, invited speaker Jay Jung has been a senior staff process integration engineer at Omnivision Technologies, Inc. Prior to this he was a TCAD manager and senior pixel engineer with Samsung from 2011-2016. He obtained his PhD in physics from Ohio State University, and his MS and BS in physics from Hanyang University, South Korea.

CONFERENCE INTERACTIVE POSTER
13:00 – 13:30

ISS-070

ISS POSTER: An ultra-low-cost large-format wireless IoT camera, *Henry Dietz and Paul Eberhart, University of Kentucky (United States)*

KEYNOTE: DEPTH SENSING
Session Chair: Jon McElvain, Dolby Laboratories (United States) / Moderator: Arnaud Peizerat, CEA (France)
13:30 – 14:30

13:30   ISS-087
KEYNOTE: 2D, or not 2D, that is the question: How 3D-stacking is shaping the future of SPAD image sensors, *Edoardo Charbon, École Polytechnique Fédérale de Lausanne (Switzerland)*

Keynote speaker Edoardo Charbon (SM'00, F'17) received the Diploma from ETH Zurich, an MS from the University of California at San Diego, and his PhD from the University of California at Berkeley (1988, 1991, and 1995, respectively), all in electrical engineering and EECS. He has consulted with numerous organizations, including Bosch, X-Fab, Texas Instruments, Maxim, Sony, Agilent, and the Carlyle Group. He was with Cadence Design Systems from 1995 to 2000, where he was the architect of the company's initiative on information hiding for intellectual property protection. In 2000, he joined Canesta Inc., as the chief architect, where he led the development of wireless 3-D CMOS image sensors. Since 2002 he has been a member of the faculty of EPFL, and has been a full professor since 2015. From 2008 to 2016 he was with Delft University of Technology as chair of VLSI design. Charbon has been the driving force behind the creation of deep-submicron CMOS SPAD technology, which is mass-produced since 2015 and is present in telemeters, proximity sensors, and medical diagnostics tools. His interests span from 3-D vision, LiDAR, FLIM, FCS, NIROT to super-resolution microscopy, time-resolved Raman spectroscopy, and cryo-CMOS circuits and systems for quantum computing. He has authored or co-authored more than 400 papers and two books, and he holds 23 patents. Charbon is a distinguished visiting scholar of the W. M. Keck Institute for Space at Caltech, a fellow of the Kavli Institute of Nanoscience Delft, a distinguished lecturer of the IEEE Photonics Society, and a fellow of the IEEE.

14:10
Roundtable with Edoardo Charbon

SENSOR DESIGN II
Moderator: Jon McElvain, Dolby Laboratories (United States) / **Session Chair:** Rihito Kuroda, Tohoku Univ. (Japan)
18:15 – 19:15

18:15   ISS-091
A low-voltage 0.7 μm pixel with 6000 e- full-well capacity for a low-power CMOS image sensor, *Seung-Wook Lee, Seungwon Cha, Dongyoung Jang, Mihye Kim, Haewon Lee, Nakyung Lee, Seonok Kim, Kwanyoung Oh, Daehyung Lee, SeungHan Hong, Hana Lee, Sunghoon Oh, Donghyuk Park, Yitae Kim, and JungChak Ahn, Samsung Electronics DS (Republic of Korea)*

18:35   ISS-092
A proposal of analog correlated multiple sampling with high density capacitors for low noise CMOS image sensors, *Shunta Kamoshita, Manabu Suzuki, Rihito Kuroda, and Shigetoshi Sugawa, Tohoku University (Japan)*

18:55   ISS-093
0.8 um color pixels with wave-guiding structures for low optical crosstalk image sensors, *Yu-Chi Chang, Cheng-Hsuan Lin, Zong-Ru Tu, Jing-Hua Lee, Sheng Chuan Cheng, Ching-Chiang Wu, Ken Wu, and H. J. Tsai, VisEra Technologies Company (Taiwan)*

CONFERENCE INTERACTIVE POSTER
19:15 – 19:45

ISS-072
ISS POSTER: Estimation of any fields of lens PSFs for image simulation, *Sangmin Kim[1], Daekwan Kim[1], Kilwoo Chung[1], and JoonSeo Yim[2]; [1]Samsung Electronics Device Solutions and [2]Samsung Electronics (Republic of Korea)*

APPLICATIONS
Moderator: Rihito Kuroda, Tohoku Univ. (Japan) / **Session Chair:** Hans Reyserhove, Ceremorphic (United States)
19:45 – 20:45

19:45   ISS-066
A single chip PPG sensor with enhanced IR sensitivity for low power and small size, *Jungwook Lim[1], Jihun Kim[1], Long Yan[1], Hyunpil Noh[1], Junghyung Pyc[1], Taesub Jung[2], Jungbin Yun[1], Seungki Jung[1], Doosik Seol[1], Kyungho Lee[1], Takashi Nagano[1], and JungChak Ahn[1]; [1]Samsung Electronics Device Solutions and [2]Samsung Electronics (Republic of Korea)*

20:05   ISS-067
Under display camera Quad Bayer raw image restoration using deep learning, *Irina Kim, Yunseok Choi, Hayoung Ko, Dongpan Lim, Youngil Seo, Jeongguk Lee, Geunyoung Lee, Eundoo Heo, Seongwook Song, and SukHwan Lim, Samsung (Republic of Korea)*

20:25   ISS-068
Under display camera image recovery through diffraction compensation, *Jeongguk Lee, Yunseok Choi, Han-Sol Lee, Eundoo Heo, Dongpan Lim, Geunyoung Lee, and Seongwook Song, Samsung Electronics (Republic of Korea)*

WEDNESDAY 20 JANUARY 2021

IMAGING SYSTEMS I
Moderator: Jon McElvain, Dolby Laboratories (United States) / **Session Chair:** Peter Catrysse, Stanford University (United States)
10:15 – 11:15

10:15   ISS-120
Programmable liquid crystal apertures and filters for photographic lenses, *Henry Dietz, University of Kentucky (United States)*

10:35   ISS-121
DevCAM: An open-source multi-camera development system for embedded vision, *Dominique Meyer, Meher Birlangi, and Falko Kuester, University of California, San Diego (United States)*

10:55   ISS-122
Validation of image systems simulation technology using a Cornell box, *Zheng Lyu[1], Krithin Kripakaran[1], Max Furth[2], Eric Tang[3], Brian Wandell[1], and Joyce Farrell[1]; [1]Stanford University (United States), [2]Brighton College (United Kingdom), and [3]Henry M Gunn High School (United States)*

IMAGING SYSTEMS II

Moderator: Jon McElvain, Dolby Laboratories (United States) / **Session Chair:** Francisco Imai, Apple Inc. (United States)
11:45 – 12:45

11:45 ISS-123

Creating, weaponizing, and detecting deep fakes (Invited), *Hany Farid, University of California at Berkeley (United States)*

Invited speaker Hany Farid is a professor at the University of California, Berkeley with joint appointments in electrical engineering, computer sciences, and the school of information. His research focuses on image analysis, digital forensics, and the intersection of technology and society particularly as it pertains to online harms. He received his undergraduate degree in computer science and applied mathematics from the University of Rochester (1989), his MS in computer science from SUNY Albany, and his PhD in computer science from the University of Pennsylvania (1997). Following a two-year post-doctoral fellowship in brain and cognitive sciences at MIT, he joined the faculty at Dartmouth College in 1999 where he remained until 2019. He is the recipient of an Alfred P. Sloan Fellowship, a John Simon Guggenheim Fellowship, and is a fellow of the National Academy of Inventors.

12:15 ISS-124

Optical design and manufacturability of imaging lenses for high resolution sensors (Invited), *Gregory Hollows, Edmund Optics (United States)*

Invited speaker Gregory Hollows is the vice president of imaging at Edmund Optics, Inc., where he directs and manages Edmund's Imaging Business Unit responsible for Edmund's numerous lens offerings designed to service the demanding needs of industries such as machine vision, factory automation, life sciences, and autonomous vehicles. He is member of the Board of Directors for A3, The Association for Advancing Automation, and of the AIA, The Automated Imaging Association/Association for Advancing Imaging. At the AIA, he has served in numerous roles over the years, among them, chair of the board, education committee chair and tradeshow committee chair. A certified vision professional, Greg has taught numerous basic and advanced optics for the imaging industry. He is author of numerous technical articles and tutorials on optics and imaging and has degrees in physics and chemistry from Rutgers University.

KEYNOTE: COMPUTATIONAL CAPTURE

Moderator: Jon McElvain, Dolby Laboratories (United States) / Session Chair: Nitin Sampat, Edmund Optics, Inc (United States)
13:15 – 14:15

13:15 ISS-128

KEYNOTE: Computational photography at the point of capture on mobile cameras, *Marc Levoy, Adobe Inc. (United States)*

Keynote speaker Marc Levoy is the VMware Founders Professor of Computer Science (Emeritus) at Stanford University, and a vice president and fellow at Adobe. From 2011 until 2020 he worked at Google, most recently as a distinguished engineer in Google Research. In previous lives he worked on computer-assisted cartoon animation (1970s), volume rendering (1980s), 3D scanning (1990s), light field imaging (2000s), and computational photography (2010s). At Stanford he taught computer graphics, digital photography, and the science of art. At Google he launched Street View, co-designed the library book scanner, and led the team that created HDR+, Portrait Mode, and Night Sight for Pixel smartphones. Awards include Cornell University Charles Goodwin Sands Medal for best undergraduate thesis (1976), National Science Foundation Presidential Young Investigator (1991), ACM SIGGRAPH Computer Graphics Achievement Award (1996), and ACM Fellow (2007). His Google team's software for Pixel phones won DP Review's Innovation of the Year (2017 and 2018) and Smartphone Camera of the Year (2019), Mobile World Congress's Disruptive Device Innovation Award (2019), and other awards.

13:55
Roundtable with Marc Levoy

THURSDAY 21 JANUARY 2021

PLENARY: THE DEVELOPMENT OF INTEGRAL COLOR IMAGE SENSORS AND CAMERAS

Session Chair: Jonathan B. Phillips, Google Inc. (United States)
10:00 – 11:10

The development of integral color image sensors and cameras
Kenneth A. Parulski, *expert consultant: mobile imaging (United States)*

Kenneth Parulski is an expert consultant to mobile imaging companies and leads the development of ISO standards for digital photography. He joined Kodak in 1980 after graduating from MIT and retired in 2012 as research fellow and chief scientist in Kodak's digital photography division. His work has been recognized with a Technical Emmy and other major awards. Parulski is a SMPTE fellow and an inventor on more than 225 US patents.

MONDAY 25 JANUARY 2021

PLENARY: MAKING INVISIBLE VISIBLE

Session Chair: Jonathan B. Phillips, Google Inc. (United States)
10:00 – 11:10

Making invisible visible
Ramesh Raskar, *associate professor, MIT Media Lab (United States)*

Ramesh Raskar is an associate professor at MIT Media Lab and directs the Camera Culture research group. His focus is on AI and imaging for health and sustainability. They span research in physical (e.g., sensors, health-tech), digital (e.g., automated and privacy-aware machine learning), and global (e.g., geomaps, autonomous mobility) domains. He received the Lemelscn Award (2016), ACM SIGGRAPH Achievement Award (2017), DARPA Young Faculty Award (2009), Alfred P. Sloan Research Fellowship (2009), TR100 Award from MIT Technology Review (2004), and Global Indus Technovator Award (2003). He has worked on special research projects at Google [X] and Facebook and cc-founded/advised several companies.

WEDNESDAY 27 JANUARY 2021

PLENARY: REVEALING THE INVISIBLE TO MACHINES WITH NEUROMORPHIC VISION SYSTEMS: TECHNOLOGY AND APPLICATIONS OVERVIEW

Session Chair: Radka Tezaur, Intel Corporation (United States)
10:00 – 11:10

Revealing the invisible to machines with neuromorphic vision systems: Technology and applications overview
Luca Verre, *CEO and cc-founder, Prophesee (France)*

Luca Verre is cc-founder and CEO of Prophesee, the inventor of the world's most advanced neuromorphic vision systems. Verre is a World Economic Forum technology pioneer. His experience includes project and product management, marketing, and business development roles at Schneider Electric. Prior to Schneider Electric, Verre worked as a research assistant in photonics at the Imperial College of London. Verre holds a MSc in physics, electronic and industrial engineering from Politecnico di Milano and Ecole Centrale and an MBA from Institut Européen d'Administration des Affaires, INSEAD.