# AOPC 2017: Space Optics and Earth Imaging and Space Navigation

Carl Nardell Suijian Xue Huaidong Yang Editors

4–6 June 2017 Beijing China

Sponsored by SPIE Chinese Society for Optical Engineering (China)

Organized by Chinese Society for Optical Engineering (China) Photoelectronic Technology Committee, Chinese Society of Astronautics (China) Department of Cooperation and Coordination for Industry, Academe and Research, CHIA (China) Science and Technology on Low-light-level Night Vision Laboratory (China) Science and Technology on Electro-Optical Information Security Control Laboratory (China)

Published by SPIE

Volume 10463

Proceedings of SPIE 0277-786X, V. 10463

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

AOPC 2017: Space Optics and Earth Imaging and Space Navigation, edited by Carl Nardell, Suijian Xue, Huaidong Yang Proc. of SPIE Vol. 10463, 1046301 · © 2017 SPIE · CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2306549

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 SPIEDigitalLibrary.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 AOPC 2017: Space Optics and Earth Imaging and Space Navigation, edited by Carl Nardell, Suijian Xue, Huaidong Yang, Proceedings of SPIE Vol. 10463 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

ISSN: 0277-786X ISSN: 1996-756X (electronic)

ISBN: 9781510614079 ISBN: 9781510614086 (electronic)

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 © 2017, 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 0277-786X/17/\$18.00.

Printed in the United States of America.

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



**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 seven-digit CID article numbering system structured as follows:

• The first five 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
- xi Conference Committee
- xiii Introduction

#### SPACE OPTICS AND EARTH IMAGING AND SPACE NAVIGATION

- 10463 02 Interference and deception detection technology of satellite navigation based on deep learning [10463-32]
- 10463 03 Calibration algorithm for center deviation of rotary tomography imaging [10463-18]
- 10463 04 A heuristic constraint programmed planner for deep space exploration problems [10463-13]
- 10463 05 A research on the positioning technology of vehicle navigation system from single source to "ASPN" [10463-4]
- 10463 06 Visual navigation using natural landmark based on local features [10463-15]
- 10463 07 Research on vehicle detection based on background feature analysis in SAR images [10463-29]
- 10463 08 Enriching mission planning approach with state transition graph heuristics for deep space exploration [10463-31]
- 10463 09 Decision-making method for small space aircraft navigation based on information fusion [10463-34]
- 10463 0A Spacial gyroscope calibration algorithm base on fusion filter [10463-3]
- 10463 0B **Real-time single image dehazing based on dark channel prior theory and guided filtering** [10463-59]
- 10463 OC Predicting the random drift of MEMS gyroscope based on K-means clustering and OLS RBF Neural Network [10463-22]
- 10463 0D Infrared nano-sensor based on doubly splited optomechanical cavity [10463-2]
- 10463 OE An innovative Neural-Fuzzy adaptive Kalman filter for ultra-tightly coupled GPS/INS integrated system [10463-14]
- 10463 OF Algorithm of GNSS positioning based on Doppler shift in incomplete condition of insufficient available satellites [10463-19]

10463 0G	The application and development of ultra low expansion glass-ceramic in aerospace area [10463-20]
10463 OH	A self-calibration method in single-axis rotational inertial navigation system with rotating mechanism [10463-12]
10463 01	Simulation analysis of photometric data for attitude estimation of unresolved space objects [10463-25]
10463 OJ	Modeling amplitude SAR image with the Cauchy-Rayleigh mixture [10463-23]
10463 OK	Real-time analysis for Stochastic errors of MEMS gyro [10463-17]
10463 OL	A novel power control approach of multiple GNSS spoofing signals [10463-10]
10463 OM	Research and development of a control system for multi axis cooperative motion based on PMAC [10463-9]
10463 ON	Positioning navigation and timing service applications in cyber physical systems [10463-30]
10463 00	The design of multi-core DSP parallel model based on message passing and multi-level pipeline [10463-7]
10463 OP	A clock-aided positioning algorithm based on Kalman model of GNSS receiver clock bias [10463-8]
10463 0Q	A new fault diagnosis algorithm for AUV cooperative localization system [10463-33]
10463 OR	Gravity compensation in a Strapdown Inertial Navigation System to improve the attitude accuracy [10463-5]
10463 OS	Simulation of some vital space radiation characteristics for a magnetosphere probing mission [10463-1]
10463 OT	Optical system design of CCD star sensor with large aperture and wide field of view [10463-16]
10463 OU	Robust and intelligent algorithms for TDOA localization in distributed sensor networks [10463-21]
10463 OV	Numerical simulation of optical synthetic aperture imaging system [10463-24]
10463 OW	An intelligent anti-jamming network system of data link [10463-35]
10463 OX	A BRDF statistical model applying to space target materials modeling [10463-36]
10463 OY	Motion state analysis of space target based on optical cross section [10463-37]
10463 OZ	Design of optical-mechanical structure for off-axis reflective star sensor ground calibration equipment [10463-38]

- 10463 10 Rearranging the lenslet array of the compact passive interference imaging system with high resolution [10463-39]
- 10463 11 Miniaturized star tracker for micro spacecraft with high angular rate [10463-40]
- 10463 12 Adaptive compressed sensing of remote-sensing imaging based on the sparsity prediction [10463-42]
- 10463 13 Design and analysis of push-broom optical camera's following windows [10463-43]
- 10463 14 Testing of an off-axis parabolic mirror based on hybrid compensation technology [10463-44]
- 10463 15 Design of control system for piezoelectric deformable mirror based on fuzzy self-adaptive PID control [10463-45]
- 10463 16 Adaptive optics correction based on stochastic parallel gradient descent technique using Zernike polynomials [10463-46]
- 10463 17 Modal simulation and experimental verification of space-borne two dimensional turntable [10463-47]
- 10463 18 Research on the method of improving the accuracy of CMM (coordinate measuring machine) testing aspheric surface [10463-48]
- 10463 19 Research on convergence efficiency optimization of large and middle-scale silicon carbide mirrors [10463-50]
- 10463 1A Signal noise ratio analysis and on-orbit performance estimation of a solar occultation Fourier transform spectrometer [10463-51]
- 10463 1B Space-based detection of space debris by photometric and polarimetric characteristics [10463-58]
- 10463 1C Optical system design of lunar rover navigation camera [10463-60]
- 10463 1D Variable curvature mirror having variable thickness: design and fabrication [10463-62]
- 10463 1E High-precision processing and detection of the high-caliber off-axis aspheric mirror [10463-63]
- 10463 1F Thermal effects of optical antenna under the irradiation of laser [10463-64]
- 10463 1G High-resolution wavefront reconstruction using the frozen flow hypothesis [10463-65]
- 10463 1H Efficiency calibration of infrared single photon detectors by means of twin photons [10463-67]
- 10463 11 Optomechanical integrated simulation of Mars medium resolution lens with large field of view [10463-68]

- 10463 1K Temperature and nonlinearity correction methods for commercial CCD array spectrometers used in field [10463-70]
- 10463 1L Stray light and bandwidth corrections for commercial CCD array spectrometers [10463-71]
- 10463 1M Dwell time method based on Richardson-Lucy algorithm [10463-72]
- 10463 1N A design of an on-orbit radiometric calibration device for high dynamic range infrared remote sensors [10463-73]
- 10463 10 Lightweight structure design for supporting plate of primary mirror [10463-74]
- 10463 1P On advanced configuration enhance adaptive system optimization [10463-75]
- 10463 1Q Nonlinearity measurement of silicon detector and PMT detector [10463-76]
- 10463 1R The modeling and analysis of the image-rotation of the stabilizing mirror based on the spatial coordinate transformation [10463-77]
- 10463 15 Design of high precision optical image stabilization system for high resolution Earth observation remote sensing [10463-79]
- 10463 1T Analysis and design of segment control system in segmented primary mirror (Invited Paper) [10463-80]
- 10463 10 Lunar-edge based on-orbit modulation transfer function (MTF) measurement [10463-82]
- 10463 1V A new effective combined design method of optics and baffles for low obscuration ratio three-mirror system [10463-83]
- 10463 1W Influence of the platform jitter on intensity fluctuation for laser launch system [10463-84]
- 10463 31 Frequency division multiplexed multi-color fluorescence microscope system [10463-800]

### **Authors**

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five 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.

Ai, Jie, 0D Chen, Hongliang, 1P Chen, Hongyue, 05 Chen, Jianhua, OL Chen, Junjie, 0G Chen, Mo, 1T Chen, Shuxin, OL Chen, Su, 13 Chen, Weiyi, 02 Chen, Yu, 05 Chen, Yuanpei, OH Cheng, Ying, 1U Chong, Xin, 12 Cong, Wang, 18 Cui, Kai, 17 Cui, Pingyuan, 04, 08 Dai, Caihong, 1K, 1L, 1Q Dai, Chen, 1E Deng, Pingke, 02 Ding, Jiaoteng, 1D Ding, Quanxin, 1P Dong, Deng-feng, 0M Dong, Lijing, 0G Du, Hang, 19 Du, Qingyu, 0J Du, Xiaoping, Ol Dun, Xiong, 1N Fan, Chengyu, 1W Fan, Xiangrui, OW Fang, Jiaqi, OU Feng, Yu, 1H Gao, Shibo, 06 Gao, Wei, 15 Gong, Jie, 1D Gou, Ruixin, Ol Guo, Chunjie, 1P Guo, Jiu-yuan, OF Guo, Kang, 0A Guo, Xiao-xiao, 0M Han, Ximeng, 14 He, Wenjing, 00 He, Zhiyi, OU Hou, Lizhou, 1A Hu, Haibo, 1S Hu, Heng, Ol Hu, Jian, 00 Hu, Ruiguang, 06, 07 Huang, Huang, OJ Huang, Sen, OL

Huang, Tong, 1W Jian, Cui, OU Jiang, Aimin, 1S Jiang, Bo, 1M Jiang, Hu, OS Jiana, Lun, OT Jiang, Xiao, 04 Jiang, Yongliang, 14 Jin, Guo Fan, 31 Jin, Hao, 08 Jin, Weigi, 1N Le, Vu Nam, 31 Li, Ang, 18, 1E Li, Baosheng, 03 Li, Bicen, 1A Li, Bin, 1T Li, Chuanrong, 00 Li, Chunlei, 0G Li, Fu, 1F Li, Haizhou, 05 Li, Jianhua, 11 Li, Kui, OH Li, Ling, 1K, 1L, 1Q Li, Shengyi, 19 Li, Tao, OD Li, Xilong, 12 Li, Xu Peng, 10 Li, Yang, 1V Li, Yaping, 02 Li, Ying-chao, OT Li, Zhi, OX, OY Li, Zhifeng, 11 Li, Zhiguo, 17 Li, Zishen, OP Liang, Yonghui, 1G Liao, Zhibo, 1V Lin, Jingyong, OW Lin, Shangmin, 1C Liu, Bei, 10 Liu, Chenghao, 0X, 0Y Liu, Dali, 1V Liu, Dong, 14 Liu, Gang, 10 Liu, Hao, Ol Liu, Hua, 1P Liu, Jiaqi, 09, 11 Liu, Jiarun, OW Liu, Jie, 1C Liu, Jin, 1G

Liu, Meiying, 13, 1C Liu, Peng, 09 Liu, Shanlin, 03 Liu, Xinlong, 1U Liu, Xuewen, 1G Liu, Yang, 1C Liu, Yang, 1R Liu, Yunqing, OZ Liu, Zhaohui, 17 Liu, Zhuang, OT Liu, Zhuowei, OL Lu, Xiaoyun, 1B Ma, Donglin, 14 Ma, Huimin, 16 Ma, Jingfang, 0D Ma, Liehua, OD Ma, Zhen, 1M Meng, Fanrong, 00 Miao, Zhiyong, OK, OQ Mu, Lei, 09 Niu, Jingyu, 00 Niu, Zhenhong, 11 Pan, Yue, 1B Pang, Shuxia, 1B, 1C Peng, Qiangqiang, OJ Qiang, Li, 14 Qiao, Chunhong, 1W Qiao, Yan, 16 Qu, Hemeng, 1R Qu, Yan Jun, 10 Qu, Yi, 02, 0N Shen, Chunshan, 16 Shen, Le, 1D Shen, Yang, 1B Sheng, Yicheng, 1N Shi, Hongyang, OK, OQ Song, Ci, 19 Song, Zongxi, 10, 15 Sun, Qian, 05 Sun, Yi, 1F, 11 Tang, Bo, 07 Tian, Qichen, 0X, 0Y Wang, Caiqin, 1A Wang, Chao, OT Wang, Feng, 1C Wang, Helong, 1P Wang, Hu, 13, 1B, 1C Wang, Jun, OR Wang, Lingcao, OH Wang, Lingguang, 13 Wang, Lingjie, 1R Wang, Wei, 10 Wang, Weidong, 09 Wang, Xiao, 10 Wang, Xingshu, OR Wang, Yanfei, 1K, 1L, 1Q Wang, Yang, Ol Wang, Yicheng, 03 Wang, Yipeng, 0G Wang, Yulei, 14

Wang, Zhen-yu, OC Wang, Zhile, OV Wen, Desheng, 10 Wu, Hongbo, 1R Wu, Jiabao, OE Wu, Xiaojing, ON Wu, Zhifeng, 1K, 1L, 1Q Xian, Hao, 1T Xiang, Yanjun, OD Xiao, Liping, 06, 07 Xiao, Nan, 15 Xiao, Si, 1N Xie, Xiaopeng, 1D Xu, Can, 0X, 0Y Xu, Fan, 0A Xu, Guangzhou, 11 Xu, Jieping, 1G Xu, Liang, 1D Xu, Lingdi, 18, 1E Xu, Pengmei, 1A Xu, Rui, 04, 08 Xu, Weicai, 14 Xu, Wenming, 08 Xue, Yaoke, 13, 1C Yan, Lisong, 14 Yang, Huai Dong, 31 Yang, Jianfeng, 1F, 11 Yang, Senlin, 12 Yang, Shuai, OR Yang, Wenqiang, 1F, 11 Yang, Yongying, 14 Yao, Yinwei, OJ Yi, Hongwei, 1U You, Taihua, OA Yu, Guangwei, 0G Yu, Jinpei, OS Yu, Wenhao, 1T Yuan, Hong, OP Yue, Xiang, 03 Yun, Hongquan, 07 Zeng, Lingchuan, ON Zhang, Bochuan, 07 Zhang, Cong, 07 Zhang, Jianping, 1R Zhang, Jing, 05 Zhang, Jinghui, 1W Zhang, Jiqing, 0G Zhang, Li-jie, OC Zhang, Pengfei, 1W Zhang, Shuqing, OV Zhang, Si Chun, 31 Zhang, Tingcheng, 1V Zhang, Weiyi, 06 Zhang, Wenying, OZ Zhang, Xiaoguang, 02 Zhang, Xiao-lin, OF Zhang, Xibin, 1C Zhang, Xin Rong, 31 Zhang, Xin, 1R Zhang, Yangyang, 1H

Zhang, Yeping, 0D Zhang, Yi, 0K, 0Q Zhang, Yingjie, 1E Zhang, Yongqiang, 17 Zhang, Yuanyuan, 0G Zhang, Zan, 0B Zhao, Hui, 1D Zhao, Pengyu, 1H Zhou, Chenghao, 0V Zhou, Chenghao, 0V Zhou, Chunmei, 0W Zhou, Chunmei, 0W Zhou, Chunmei, 0W Zhou, Feng, 1N Zhou, Jiang, 17 Zhou, Liang, 17 Zhou, Liwei, 1P Zhou, Wei-hu, 0M Zhu, Haoran, 0Z Zhu, Jing, 0R Zhu, Lingyao, 0P Zhu, Shengying, 08 Zou, Dinghua, 17

## **Conference Committees**

#### **Conference** Chairs

Guangjun Zhang, Beihang University (China) Byoungho Lee, Seoul National University (Korea, Republic of)

#### Conference Committee

Desheng Jiang, Wuhan University of Technology (China) Hequan Wu, Chinese Academy of Engineering (China) Jianguan Yao, Tianjin University (China) Jianwei Pan, University of Science and Technology of China (China) Junhao Chu, Shanghai Institute of Technical Physics, CAS (China) Junen Yao, Beihang University (China) Lijun Wang, Changchun Institute of Optics, Fine Mechanics and Physics, CAS (China) Lin Li, The University of Manchester (United Kingdom) Liwei Zhou, Beijing Institute of Technology (China) Min Gu, RMIT University (Australia) **Shibin Jiang**, AdValue Photonics Inc. (United States) Toyohiko Yatagai, Utsunomiya University (Japan) Wei Wang, Beijing Institute of Aerospace Control Devices, CASC (China) Weidou Ni, Tsinghua University (China) Zuyan Xu, Technical Institute of Physics & Chemistry, CAS (China)

#### Program Committee

Anand Krishna Asundi, Nanyang Technological University (Singapore) **Bing Zhao**, Jilin University (China) Byoungho Lee, Seoul National University (Korea, Republic of) Carl Nardell, Google Skybox Imaging (United States) Chunhua Shen, The University of Adelaide (Australia) Haimei Gong, Shanahai Institute of Technical Physics, CAS (China) Honghai Liu, University of Portsmouth (United Kingdom) Huaidong Yang, Tsinghua University (China) Huijie Zhao, Beihang University (China) Jannick Rolland, Institute of Optics, University of Rochester (United States) Jin Lu, Tianjin Jinhang Institute of Technical Physics (China) Jin Yu, Université Claude Bernard Lyon 1 (France) Jinxue Wang, SPIE Lijun Wang, Changchun Institute of Optics, Fine Mechanics and Physics, CAS (China) Lin Li, The University of Manchester (United Kingdom) Lan Jiang, Tsinghua University (China)

Long Zhang, Shanghai Institute of Optics and Fine Mechanics, CAS (China) Mengxia Xie, Beijing Normal University (China) Min Gu, RMIT University (Australia) Min Qiu, Zhejiang University (China) Shibin Jiang, AdValue Photonics Inc. (United States) Suijian Xue, National Astronomical Observatories, CAS (China) Tsutomu Shimura, The University of Tokyo (Japan) Wei Hang, Xiamen University (China) Wei Wang, Beijing Institute of Aerospace Control Devices, CASC (China) Weibiao Chen, Shanghai Institute of Optics and Fine Mechanics, CAS (China) Wolfgang Osten, Universität Stuttgart (Germany) Xiandeng Hou, Sichuan University (China) Xiangping Li, Jinan University (China) Xiaocong Yuan, Shenzhen University (China) Xiaodi Tan, Beijing Institute of Technology (China) Yadong Jiang, University of Electronic Science and Technology of China (China) Yanbiao Liao, Tsinghua University (China) Yong Bi, Academy of Opto-Electronics, CAS (China) Yongtian Wang, Beijing Institute of Technology (China) **Zhe Wang**, Tsinghua University (China) Zhiping Zhou, Peking University (China)

#### Session Chairs

- 1 Carl Nardell, Google Terra Bella (United States)
- 2 Larry Gordley, Global Atmospheric Technologies and Sciences (United States)
- 3 **Yang Huaidong**, Tsinghua University (China)
- 4 Hao Lei, Shanghai Astronomical Observatory, CAS (China)

## Introduction

Applied Optics and Photonics China (AOPC2017) is the annual conference of the CSOE, and one of the largest academic and industry activities in the field of optical and optoelectronic technology in China. The organization committee has built a platform of academic exchanges, industry exhibitions, and cooperation negotiations in one. There are 8 technical conferences, 7 themes of the Exhibition and approximately 600 technical presentations. We sincerely hope that the research and development of optoelectronic technology are promoted, and the international cooperation between industry and the optical and optoelectronic fields are enhanced.

AOPC2017 is technically co-sponsored by the Chinese Society for Optical Engineering, the Optical Society of Korea (OSK), Optics and Photonics Society of Singapore (OPSS), European Optical Society (EOS), Optical Society of Japan (OSJ) and SPIE. There are also 60 cooperative organizers to support the conference. We received over 1209 contributions from more than 15 countries, including the United States, the United Kingdom, Germany, France, Spain, Australia, Canada, Mexico, Brazil, Japan, Korea, Thailand, Singapore, the Russian Federation, China, and more. There are more than 700 presentations published in the Proceedings of SPIE. After careful discussion, we suggested four keynote speeches which are presented by famous scientists from Germany, Australia, Japan and China. 138 excellent invited talks were presented, 45 are from outside of China. Their presentations reflect first-class research in the field of optics and photonics technology. On behalf of the Organization Committee of AOPC, I express thanks to all the invited speakers and authors for their contributions and support of the conference.

Finally, on behalf of Prof. Zhuang Songlin, and other co-chairmen, and the Organization Committee of AOPC, I would like to heartily thank our sponsors and cooperating organizers for all they have done for the conference, the participants and friends for their interests and efforts in helping us to make the conference a success, the program committee for their effective work and valuable advice, and especially the AOPC2017 Secretariat and the staff of SPIE for their tireless effort and outstanding services in preparing the conference and publishing the Proceedings.

We wish AOPC2017 great success! Hope to see you next year!

Guofan Jin