PROCEEDINGS OF SPIE

Sensors and Systems for Space Applications II

Richard T. Howard
Pejmun Motaghedi
Editors

17–18 March 2008
Orlando, Florida, USA

Sponsored and Published by
SPIE

Volume 6958

Proceedings of SPIE, 0277-786X, v. 6958

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

The papers included 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. The papers published in these proceedings 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 this book:
Author(s), "Title of Paper," in *Sensors and Systems for Space Applications II*, edited by Richard T. Howard, Pejmun Motaghedi, Proceedings of SPIE Vol. 6958 (SPIE, Bellingham, WA, 2008) Article CID Number.

ISSN 0277-786X
ISBN 9780819471499

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 © 2008, 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/08/$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

SPIEDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- 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. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

vii *Conference Committee*

ix *Introduction*

xi *Deep space flight of Hayabusa asteroid explorer (Plenary Paper) [6960-100]*
H. Kuninaka, J. Kawaguchi, Japan Aerospace Exploration Agency (Japan)

ORBITAL EXPRESS I

6958 03 **Orbital Express program summary and mission overview (Invited Paper)** [6958-02]
R. B. Friend, The Boeing Co. (USA)

6958 06 **Orbital Express mission operations planning and resource management using ASPEN** [6958-06]
C. Chouinard, R. Knight, G. Jones, D. Tran, Jet Propulsion Lab. (USA)

ORBITAL EXPRESS II

6958 07 **NextSat on-orbit experiences** [6958-07]
C. R. Randall, B. S. Porter, C. Stokley, K. Epstein, D. Kaufman, Ball Aerospace & Technologies Corp. (USA)

6958 08 **Orbital Express fluid transfer demonstration system** [6958-08]
S. Rotenberger, D. SooHoo, G. Abraham, Northrop Grumman Corp. (USA)

6958 09 **Autonomous robotic operations for on-orbit satellite servicing** [6958-09]
A. Ogilvie, J. Allport, M. Hannah, J. Lymer, MDA (Canada)

6958 0A **Orbital Express Autonomous Rendezvous and Capture Sensor System (ARCSS) flight test results** [6958-10]
M. R. Leinz, C.-T. Chen, M. W. Beaven, T. P. Weismuller, D. L. Caballero, W. B. Gaumer, P. W. Sabasteanski, P. A. Scott, M. A. Lundgren, The Boeing Co. (USA)

6958 0C **Modeling, simulation, testing, and verification of the Orbital Express Autonomous Rendezvous and Capture Sensor System (ARCSS)** [6958-12]
M. R. Leinz, C.-T. Chen, P. Scott, W. Gaumer, P. Sabasteanski, M. Beaven, The Boeing Co. (USA)

6958 0D **Comparison of navigation solutions for autonomous spacecraft from multiple sensor systems** [6958-13]
J. LeCroy, D. Hallmark, P. Scott, The Boeing Co. (USA); R. Howard, NASA Marshall Space Flight Ctr. (USA)

6958 0E **On-orbit performance of the Orbital Express Capture System** [6958-14]
P. Motaghedi, The Boeing Co. (USA)

VIDEO AND SPACE DATA PROCESSING

6958 0H **3D position and velocity vector computations of objects jettisoned from the International Space Station using close-range photogrammetry approach** [6958-17]
V. Papanyan, E. Oshel, NASA Johnson Space Ctr. (USA) and Jacobs Technology (USA); D. Adamo, United Space Alliance, LLC (USA)

6958 0I **ULTOR passive pose and position engine for spacecraft relative navigation** [6958-18]
S. J. Hannah, Advanced Optical Systems, Inc. (USA)

6958 0J **Optical SAR processor for space applications** [6958-19]
P. Bourqui, INO (Canada); B. Harnisch, European Space Agency (Netherlands); L. Marchese, A. Bergeron, INO (Canada)

6958 0K **Phase retrieval in sparse aperture systems with phase diversity: a trade space study** [6958-20]
B. J. Daniel, Rochester Institute of Technology (USA); M. R. Bolcar, Institute of Optics, Univ. of Rochester (USA); J. R. Schott, Rochester Institute of Technology (USA); J. R. Fienup, Institute of Optics, Univ. of Rochester (USA)

SENSOR DEVELOPMENT

6958 0M **Fiber optic microsensor hydrogen leak detection system on Delta IV launch vehicle** [6958-22]
A. A. Kazemi, J. W. Goepp, The Boeing Co. (USA); D. B. Larson, M. E. Wuestling, NextGen Research Corp. (USA)

6958 0N **Optical detection of formaldehyde** [6958-23]
K. D. Patty, D. A. Gregory, Univ. of Alabama in Huntsville (USA)

6958 0O **A radiation-hardened high-resolution optical encoder for use in aerospace applications** [6958-24]
D. K. Mitchell, MicroE Systems, GSI Group (USA)

6958 0P **Uncooled detector development for space application** [6958-25]
W. Rabaud, CEA-LETI, MINATEC (France); M. Vilain, ULIS (France); J. Meilhan, CEA-LETI, MINATEC (France); T. Garret, ULIS (France); G. Hopkinson, Surrey Satellite Technology Ltd. (United Kingdom); M. S. Bentley, S. Kraft, cosine Research B.V. (Netherlands); O. Legras, ULIS (France); P. Castelein, CEA-LETI, MINATEC (France)

SPACECRAFT: SENSORS, TESTING, AND CONTROL

6958 0Q **Design and characterization of uniform spectral radiance source for test and calibration of radiometers used for KOPMSAT-3** [6958-26]
V. Mahajan, Labsphere, Inc. (USA); D.-J. Jung, Korea Aerospace Research Institute (South Korea)

6958 0R **Ground testing the Hydra AR&D sensor system** [6958-27]
S. R. Granade, F. D. Roe, Advanced Optical Systems, Inc. (USA)

6958 0S **Rendezvous lidar sensor system for terminal rendezvous, capture, and berthing to the International Space Station** [6958-28]
A. C. M. Allen, C. Langley, R. Mukherji, A. B. Taylor, M. Umasuthan, MDA Space Missions (Canada); T. D. Barfoot, Univ. of Toronto (Canada)

6958 0T **Space telemetric panomorph imaging system for micro/nano satellite** [6958-30]
S. Thibault, ImmerVision (Canada); E. Harvey, InnoveSpace (Canada)

Author Index

Conference Committee

Symposium Chair

Larry B. Stotts, Defense Advanced Research Projects Agency (USA)

Symposium Cochair

Ray O. Johnson, Lockheed Martin Corporation (USA)

Program Track Chairs

Thomas George, ViaLogy Corporation (USA)
Peter Tchoryk, Jr., Michigan Aerospace Corporation (USA)

Conference Chairs

Richard T. Howard, NASA Marshall Space Flight Center (USA)
Pejmun Motaghedi, The Boeing Company (USA)

Program Committee

Edmund C. Baroth, Jet Propulsion Laboratory (USA)
Brian Buckley, Consultant (USA)
Richard Cohn, Air Force Research Laboratory (USA)
Michael D. Cornelius, ATK Thiokol (USA)
N. Glenn Creamer, Naval Research Laboratory (USA)
Michael E. Dobbs, ITT Industries, Inc. (USA)
Charles J. Finley, Air Force Research Laboratory (USA)
Sivaram P. Gogineni, Innovative Scientific Solutions, Inc. (USA)
Stephen R. Granade, Advanced Optical Systems, Inc. (USA)
Shahid Habib, NASA Goddard Space Flight Center (USA)
Scott Hyde, ATK Mission Research (USA)
Jeffrey L. Janicik, Innoflight Inc. (USA)
Valentin Korman, Madison Research Corporation (USA)
Daniel Leo Lau, University of Kentucky (USA)
Eric M. Miller, General Dynamics Advanced Information Systems (USA)
Simon Nolet, Massachusetts Institute of Technology (USA)
Robert D. Richards, Optech, Inc. (Canada)
Timothy E. Rumford, Orbital Sciences Corporation (USA)
Sam Sims, SMC Det 12 Space Test Program (USA)
Robert H. Smith, General Dynamics C4 Systems (USA)
Lon M. Stevens, ATK Thiokol (USA)
Stanley D. Straight, Air Force Research Laboratory (USA)
Amanda Vaughn, Air Force SMC/SYZ (USA)

Michael D. Watson, NASA Marshall Space Flight Center (USA)
John T. Wiley, Jr., NASA Marshall Space Flight Center (USA)

Session Chairs

1 Orbital Express I
Manny R. Leinz, The Boeing Company (USA)

2 Orbital Express II
Pejmun Motaghedi, The Boeing Company (USA)

3 Sensor Development I
Richard T. Howard, NASA Marshall Space Flight Center (USA)

4 Video and Space Data Processing
Andrew C. M. Allen, MacDonald, Dettwiler and Associates Ltd. (Canada)

5 Sensor Development II
Stephen R. Granade, Advanced Optical Systems, Inc. (USA)

6 Spacecraft: Sensors, Testing, and Control
Richard T. Howard, NASA Marshall Space Flight Center (USA)

Introduction

This was the second year for the Sensors and Systems for Space Applications conference, and it was the fifth year for a separate session on space sensors. The Sensors and Systems for Space Technologies conference included papers concerning spaceborne sensors, propulsion sensors, spacecraft platforms and infrastructure, and modeling, simulation, and verification of space-based systems. As part of the Space Technologies and Operations track at the 2007 Defense and Security symposium, the Sensors and Systems for Space Technologies conference covered important parts of any space operation – How do you model sensors and systems? How do you verify and test them? How well do they work on orbit? This year's conference answered those questions in a variety of ways. In addition, this year had a full day focused on various aspects of the Orbital Express mission (which was funded by DARPA, Boeing, and NASA.)

The keynote speaker this year was Lt. Col. Fred Kennedy of DARPA, final program manager for Orbital Express, a project that launched two satellites in orbit in March 2007 and operated them in a number of experiments until July 2007. He talked about the Orbital Express mission, which performed experiments testing all of the different capabilities that a satellite servicing system might need: fluid transfer, orbital replacement unit transfer (such as batteries and computers), a robot arm, a capture mechanism, and sensors for automated rendezvous and docking. These technologies have been in development and testing on the ground for many years, but this was the first United States experiment to put them all together on orbit in a completely autonomous operation.

Overall, there are 21 papers in these proceedings, covering sensors, systems, methodologies, and technologies ranging from individual components all the way up to full operational sensors and systems as well as laboratory work in sensor analysis and theoretical research.

Many of the theoretical and laboratory technologies presented in previous years were back this year with updates and improvements, and it has been very nice to see the progress of sensors, systems, and technologies over the years this conference has been in place. Several items first presented two or three years ago have now been flown in space. Space operations are a key element in the future of companies and countries, both in defense and in expanding the use of space for civil purposes. The Sensors and Systems for Space Technologies II conference contributes to the future by getting professionals together to hear one another's approaches to problems and allowing technologists to discuss innovative ideas.

We want to thank all of the authors for their time and energy in getting papers and presentations to the conference, and we want to thank the program

committee for their efforts in encouraging authors. Without your hard work, this conference would not have been a success. In addition, we would like to thank SPIE for supporting the Space Technologies track and for all their assistance in bringing everything together. Finally, thank you to all of you who attended the sessions, asked interesting questions, and prompted further discussions both during and after the sessions.

Richard T. Howard
Pejmun Motaghedi