PROCEEDINGS OF SPIE

Thermosense: Thermal Infrared Applications XXXIX

Paolo Bison
Douglas Burleigh
Editors

10–13 April 2017
Anaheim, California, United States

Sponsored and Published by
SPIE

Volume 10214

Proceedings of SPIE 0277-786X, V. 10214

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

Thermosense: Thermal Infrared Applications XXXIX, edited by Paolo Bison, Douglas Burleigh, Proc. of SPIE Vol. 10214, 1021401 · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2280659

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 *Thermosense: Thermal Infrared Applications XXXIX*, edited by Paolo Bison, Douglas Burleigh, Proceedings of SPIE Vol. 10214 (SPIE, Bellingham, WA, 2017) Seven-digit Article CID Number.

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

ISBN: 9781510609297
ISBN: 9781510609303 (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.

SPIE. DIGITAL LIBRARY
SPIEDigitalLibrary.org

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*

ix Conference Committees

xiii *Introduction*

STANDARDS CERTIFICATIONS AND GUIDELINES

10214 02 **A 2016 update on standards and guidelines relevant to thermographers** [10214-2]

FIRE ANALYSIS AND DETECTION

10214 04 **Flame filtering and perimeter localization of wildfires using aerial thermal imagery** [10214-4]

10214 05 **Object localization in handheld thermal images for fireground understanding** [10214-5]

ADDITIVE MANUFACTURING I

10214 07 **Measurement of process dynamics through coaxially aligned high speed near-infrared imaging in laser powder bed fusion additive manufacturing** [10214-7]

ADDITIVE MANUFACTURING II

10214 08 **Micro-scale thermal imaging of CO_2 absorption in the thermochemical energy storage of Li metal oxides at high temperature** [10214-8]

10214 09 **Thermal analysis of fused deposition modeling process using infrared thermography imaging and finite element modeling** [10214-9]

10214 0A **Life cycle monitoring of lithium-ion polymer batteries using cost-effective thermal infrared sensors with applications for lifetime prediction** [10214-10]

BIOLOGICAL AND MEDICAL APPLICATIONS

10214 0B **Thermographic image analysis for classification of ACL rupture disease, bone cancer, and feline hyperthyroid, with Gabor filters** [10214-11]

10214 0D **Non-invasive characterization of normal and pathological tissues through dynamic infrared imaging in the hamster cheek pouch oral cancer model** [10214-13]

10214 0E **About possibility of temperature trace observing on a human skin through clothes by using computer processing of IR image** [10214-14]

10214 0G **Pulse compression favourable aperiodic infrared imaging approach for non-destructive testing and evaluation of bio-materials** [10214-16]

NDT AND SIGNAL PROCESSING

10214 0H **Thermal inspection of a composite fuselage section using a fixed eigenvector principal component analysis method** [10214-17]

10214 0I **Numerical and experimental analyses for natural and non-natural impacted composites via thermographic inspection, ultrasonic C-scan and terahertz imaging** [10214-18]

VIBRO-THERMOGRAPHY AND THERMOMECHANICS

10214 0L **Characterizing open and non-uniform vertical heat sources: towards the identification of real vertical cracks in vibrothermography experiments** [10214-21]

10214 0M **Fatigue damage evaluation of short fiber CFRP based on phase information of thermoelastic temperature change** [10214-22]

10214 0N **Highly efficient ultrasonic vibrothermography for detecting impact damage in hybrid composites** [10214-23]

10214 0O **High-speed and high-definition infrared imaging for material characterization in experimental mechanics** [10214-24]

10214 0P **Non-destructive thermo-mechanical behavior assessment of glass-ceramics for dental applications** [10214-25]

10214 0Q **Energetic approach based on IRT to assess plastic behaviour in CT specimens (Best Student Paper Award)** [10214-26]

NDT AND MATERIAL EVALUATION

10214 0S **Thermographic investigations of metal inclusions in 3D printed samples** [10214-28]

10214 0T **Liquid nitrogen cooling in IR thermography applied to steel specimen** [10214-29]

10214 0U **Quantitative evaluation of water content in composite honeycomb structures by using one-sided IR thermography: is there any promise?** [10214-30]

10214 0W **Surface crack detection in different materials with inductive thermography** [10214-32]

10214 0X **Coating defect evaluation based on stimulated thermography** [10214-33]

MODELING HEAT CONDUCTION AND THERMOPHYSICAL PROPERTIES

10214 0Y **Application of the quadrupole method for simulation of passive thermography** [10214-35]

10214 0Z **Thermal diffusivity measurement of ring specimens by infrared thermography** [10214-37]

10214 10 **IR thermography for the assessment of the thermal conductivity of aluminum alloys** [10214-38]

10214 11 **Analysis of pulse thermography using similarities between wave and diffusion propagation** [10214-39]

BUILDINGS AND INFRASTRUCTURES

10214 12 **Infrared thermography applied to transport infrastructures monitoring: outcomes and perspectives (Best Paper Award)** [10214-40]

10214 13 **Infrared thermography applied to the study of heated and solar pavement: from numerical modeling to small scale laboratory experiments** [10214-41]

DETECTORS, IMAGING SYSTEMS AND CALIBRATION

10214 14 **Direct comparison of two pyrometers and a low-cost thermographic camera for time resolved LWIR temperature measurements** [10214-42]

10214 15 **Coaxial visible and FIR camera system with accurate geometric calibration** [10214-46]

10214 17 **Radiometric calibration of an ultra-compact microbolometer thermal imaging module** [10214-44]

10214 18 **Investigation of the influence of spatial degrees of freedom on thermal infrared measurement** [10214-45]

POSTER SESSION

10214 1A **Thermography based prescreening software tool for veterinary clinics** [10214-49]

10214 1C **Thermal conductivity characterization of polyaniline doped material for thermoelectric applications** [10214-51]

10214 1E **Infrared image correction for the reduction of background reflection** [10214-53]

10214 1F **High-performance interfaces for the implementation of various cooled IR detectors** [10214-54]

10214 1H **Modified algorithm for mineral identification in LWIR hyperspectral imagery** [10214-57]

10214 1I **Thermal NDT applying Candid Covariance-Free Incremental Principal Component Thermography (CCIPCT)** [10214-58]

10214 1J **Fatigue limit estimation of titanium alloy Ti-6Al-4V with infrared thermography** [10214-59]

10214 1K **The role of the continuous wavelet transform in mineral identification using hyperspectral imaging in the long-wave infrared by using SVM classifier** [10214-60]

10214 1L **Satellite image fusion by using a combination of IHS and HPM methods** [10214-61]

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.

Abdulkadhim, Z., 0P
Akai, Atsushi, 1J
Altenburg, Simon J., 14
Alvandipour, Mehrdad, 0B, 1A
Ancona, Francesco, 0Q
Arora, Vanita, 0G
Beaudoin, Georges, 1H, 1K
Bison, P., 0T, 0Z, 10, 1C
Blednov, Roman G., 0E
Boldrini, S., 1C
Bolduc, Sean, 0H
Bortolin, A., 0T, 0Z
Cadelano, G., 0T, 0Z
Calliari, I., 10
Castelo, A., 0L
Celorrio, R., 0L
Chamberland, Martin, 1H, 1K
Chulkov, A. O., 0U
Crinière, A., 12
Dahal, Rohini, 0B, 1A
De Finis, Rosa, 0Q
Derusova, D. A., 0N
Djupkep Dizeu, Frank Billy, 18
Druzhinin, N. V., 0N
Dua, Geetika, 0G
Dumoulin, J., 12, 13
Famengo, A., 1C
Farley, Vincent, 0O
Fernandes, Henrique, 0I
Ferrarini, G., 0T, 0Z
Feteira, A. M., 0P
Fleuret, Julien R., 0I, 18
Fox, Jason C., 07
Gagnon, Marc-André, 0O
Galietti, Umberto, 0Q, 0X
Genest, Marc, 0I
Gershenson, M., 11
Gorosmendi, I., 0L
Gorostegui-Colinas, E., 0L
Gregory, Elizabeth D., 0Y
Guyot, Éric, 0O
Hamada, Kenichi, 0M
Harman, Rebecca, 0H
Herrera, María S., 0D
Hsieh, Sheng-Jen, 09, 0A
Huff, Roy, 02
Huot, François, 1H, 1K
Ibarra-Castanedo, Clemente, 1H, 1I, 1K
Jalalvand, Azarakhsh, 05
Kato, Yukitaka, 08
Kobayashi, C., 1E
Kordatos, E. Z., 0P
Krankenhagen, Rainer, 14
Krauß, Matthias, 1F
Lagueux, Philippe, 0O
Lama, Norsang, 0B, 1A
Lane, Brandon M., 07
Laurie, Seth, 17
Le Touz, N., 13
Lei, Lei, 0T, 18
Liaigre, Kévin, 1H, 1K
López de Uralde, P., 0L
Maldague, Xavier P. V., 0I, 0T, 18, 1H, 1I, 1K, 1L
Malik, Anav, 0A
Marcotte, Frédérick, 0O
Marino, Dominic J., 0B, 1A
McIntosh, Gregory B., 02
Mendioroz, A., 0L
Merci, Bart, 05
Mishra, Deependra K., 0B, 1A
Monti Hughes, Andrea, 0D
Morikawa, Junko, 08
Morton, Vince, 0O
Moskovchenko, A. I., 0U
Mulaveesala, Ravibabu, 0G
Muniyappa, Amarnath, 0G
Nakamura, Yu, 0M
Nazarov, S., 10
Nekhoroshev, V. O., 0N
Nonaka, Shinichi, 0M
Nugent, Paul W., 17
Ogasawara, N., 1E
Ogino, Yuka, 15
Okutomi, Masatoshi, 15
Oswald-Tranta, Beata, 0S, 0W
Ouellet, Denis, 18
Padra, Claudio, 0D
Palumbo, Davide, 0Q, 0X
Pan, Y.-Y., 0U
Pastor, Elsa, 04
Perilli, Stefano, 0I
Planas, Eulàlia, 04
Riesland, David W., 17
Rios, Oriol, 04
Rossi, S., 0Z, 10, 1C
Sackman, Joseph, 0B, 1A
Sakagami, Takahide, 0M, 1J
Salazar, A., 0L

Salva, Natalia, 0D
Santa Cruz, Gustavo A., 0D
Sarasini, Fabrizio, 0I, 0N
Schmidt, Roland, 0S
Schwint, Amanda, 0D
Sfarra, Stefano, 0I, 0N, 18, 1I
Shaw, Joseph A., 17
Shestakov, Ivan L., 0E
Shibata, Takashi, 15
Shiozawa, Daiki, 0M, 1J
Siddiqui, Juned A., 0G
Sojasi, Saeed, 1H, 1K, 1L
Takasu, Hiroki, 08
Tamborrino, Rosanna, 0X
Tanaka, Masayuki, 15
Toullier, T., 13
Trofimov, Vladislav V., 0E
Trofimov, Vyacheslav A., 0E
Tuschl, Christoph, 0S
Umbaugh, David, 1A
Umbaugh, Scott E., 0B, 1A
Valero, Mario M., 04
Vandecasteele, Florian, 04, 05
Vavilov, V. P., 0N, 0U
Verstockt, Steven, 04, 05
Vettermann, Matthias, 1F
Vollheim, Birgit, 1F
Wachs, Marian, 1F
Winfree, William P., 0Y
Yamada, H., 1E
Yeung, Ho, 07
Yousefi, Bardia, 18, 1H, 1I, 1K
Zalameda, Joseph N., 0H, 0Y
Zamengo, Massimiliano, 08
Zhang, Hai, 0I, 18
Zhou, Xunfei, 09, 0A

Conference Committees

Symposium Chair

Majid Rabbani, Rochester Institute of Technology (United States)

Symposium Co-chair

Robert Fiete, Harris Corporation (United States)

Conference Chair

Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

Conference Co-chair

Douglas Burleigh, La Jolla Cove Consulting (United States)

Conference Program Committee

Andrea Acosta, Colbert Infrared Services (United States)
Nicolas Avdelidis, National Technical University of Athens (Greece)
Jeff R. Brown, Embry-Riddle Aeronautical University (United States)
Fred P. Colbert, Colbert Infrared Services (United States)
Amanda K. Criner, Air Force Research Laboratory (United States)
Jaap de Vries, FM Global (United States)
Ralph B. Dinwiddie, Oak Ridge National Laboratory (United States)
Sheng-Jen (Tony) Hsieh, Texas A&M University (United States)
Herbert Kaplan, Honeyhill Technical Company (United States)
Timo T. Kauppinen, VTT Technical Research Center of Finland (Finland)
Dennis H. LeMieux, Siemens Power Generation, Inc. (United States)
Monica Lopez Saenz, IRCAM GmbH (Germany)
Gregory B. McIntosh, Teasdale Consultants Ltd. (Canada)
Xavier P. V. Maldague, University Laval (Canada)
Junko Morikawa, Tokyo Institute of Technology (Japan)
Gary L. Orlove, FLIR Systems, Inc. (United States)
Beata Oswald-Tranta, Montan Universität Leoben (Austria)
G. Raymond Peacock, Temperatures.com, Inc. (United States)
Ralph A. Rotolante, Vicon Enterprises Inc. (United States)
Andres E. Rozlosnik, SI Termografía Infrarroja (Argentina)
Morteza Safai, The Boeing Company (United States)
Takahide Sakagami, Kobe University (Japan)
Steven M. Shepard, Thermal Wave Imaging, Inc. (United States)
Sami Siikanen, VTT Technical Research Center of Finland (Finland)

Gregory R. Stockton, Stockton Infrared Thermographic Services, Inc. (United States)
Vladimir P. Vavilov, National Research Tomsk Polytechnic University (Russian Federation)
Joseph N. Zalameda, NASA Langley Research Center (United States)

Conference Review Committee

Bjørn F. Andresen, RICOR Cryogenic & Vacuum Systems (Israel)
Gabor F. Fulop, Maxtech International, Inc. (United States)
Gerald C. Holst, JCD Publishing (United States)
Keith A. Krapels, U.S. Army Night Vision & Electronic Sensors Directorate (United States)
Arantza Mendioroz, Universidad del País Vasco (Spain)

Session Chairs

1 Vendor Presentations and Reception: Infrared Applications: ThermoSense XXXIX
Andres E. Rozlosnik, SI Termografía Infrarroja (Argentina)
Sheng-Jen Hsieh, Texas A&M University (United States)

2 Standards Certifications and Guidelines
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)
Gregory B. McIntosh, Teasdale Consultants Ltd. (Canada)

3 Fire Analysis and Detection
Beata Oswald-Tranta, Montan Universität Leoben (Austria)
Jaap de Vries, FM Global (United States)

4 Additive Manufacturing I
Ralph B. Dinwiddie, Oak Ridge National Laboratory (United States)
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

5 Additive Manufacturing II
Ralph B. Dinwiddie, Oak Ridge National Laboratory (United States)
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

6 Biological and Medical Applications
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

7 NDT and Signal Processing
Xavier P. V. Maldague, University Laval (Canada)
Joseph N. Zalameda, NASA Langley Research Center (United States)

8 Vibro-Thermography and Thermomechanics
Takahide Sakagami, Kobe University (Japan)
Arantza Mendioroz, Universidad del País Vasco (Spain)

9 NDT and Material Evaluation
Douglas Burleigh, La Jolla Cove Consulting (United States)
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

10 Modeling Heat Conduction and Thermophysical Properties
Steven M. Shepard, Thermal Wave Imaging, Inc. (United States)
Paolo Bison, Consiglio Nazionale delle Ricerche (Italy)

11 Buildings and Infrastructures
Sheng-Jen Hsieh, Texas A&M University (United States)

12 Detectors, Imaging Systems and Calibration
Junko Morikawa, Tokyo Institute of Technology (Japan)
Gary L. Orlove, FLIR Systems, Inc. (United States)

Introduction

The Thermosense conference continues to play a significant role in assessing the state-of-the-art, current developments, and future trends in the applications of infrared thermography.

This year, for the first time, Thermosense was held in Anaheim, California (United States), on 9–13 April, 2017.

The international Thermosense community of academic scientists, industry professionals, and students submitted 62 abstracts and made 46 presentations. Countries represented this year included Argentina, Canada, India, Japan, Mexico, Russia, Tajikistan, and the United States, along with a contingent of researchers from European countries including Austria, Belgium, France, Germany, Italy, and the United Kingdom.

Two awards were presented for excellence in scientific achievement. The first award, for the best overall paper, involved the use of IR thermography in large scale applications: the study of buildings and infrastructures. The second was for the best student paper, which involved small/micro scale applications: the study of thermal/mechanical properties of materials.

The awards were sponsored by FLIR Systems Inc. and IRCameras LLC respectively. These two award-winning papers demonstrated the wide range of flexibility of infrared technology.

Other topics of growing interest represented at this year's Thermosense were the use of thermography in additive manufacturing, in biological and medical applications, and in the ever-growing application of nondestructive testing (NDT).

Thermosense promotes developments in infrared technology by hosting the annual "Vendor" session, which is now in its 13th year. This very popular session is a unique opportunity for people to learn about new equipment, systems, and accessories.

Next year the historic 40th (XL) Thermosense conference will be held in Orlando, Florida (United States) where most of our conferences have been. Many of our dedicated group have been coming to Thermosense for 20–30 years, and a small number attended Thermosense 1.

We will plan some special events for Thermosense XL.

Paolo Bison
Douglas Burleigh