

PROCEEDINGS OF SPIE

# ***Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2018***

**Hoon Sohn  
Jerome P. Lynch  
Kon-Well Wang**  
*Editors*

**5–8 March 2018  
Denver, Colorado, United States**

*Sponsored by*  
SPIE

*Cosponsored by*  
OZ Optics, Ltd. (United States)  
Polytec, Inc. (United States)

*Cooperating Organizations*  
Jet Propulsion Laboratory (United States)  
Colorado Photonics Industry Association (United States)

*Published by*  
SPIE

**Volume 10598**

**Part One of Two Parts**

Proceedings of SPIE 0277-786X, V. 10598

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

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 [SPIDigitalLibrary.org](http://SPIDigitalLibrary.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 *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2018*, edited by Hoon Sohn, Jerome P. Lynch, Kon-Well Wang, Proceedings of SPIE Vol. 10598 (SPIE, Bellingham, WA, 2018) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510616929

ISBN: 9781510616936 (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](http://SPIE.org)

Copyright © 2018, 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](http://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/18/\$18.00.

Printed in the United States of America Vm7 i ffUb '5ggc WJUH'g' bWZi bXYf' JW bgY 'Zca 'GD-9.

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

**SPIE. DIGITAL  
LIBRARY**

[SPIDigitalLibrary.org](http://SPIDigitalLibrary.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

xiii	<i>Authors</i>
xvii	<i>Conference Committee</i>

## Part One

### UAV FOR STRUCTURAL INSPECTION

---

10598 02	<b>Challenging issues and solutions of bridge inspection technology using unmanned aerial vehicles [10598-1]</b>
10598 04	<b>Damage detection with an autonomous UAV using deep learning [10598-4]</b>

### ADVANCED COMPOSITE TECHNOLOGIES

---

10598 05	<b>Predicting failure from conductivity changes in piezoresistive nanocomposites [10598-5]</b>
10598 08	<b>Spatial strain measurements using a strain-sensing grid patterned from nanocomposite films [10598-8]</b>
10598 09	<b>Numerical and experimental investigation of matrix effect on sensing behavior of piezoresistive hybrid nanocomposites [10598-9]</b>

### HEALTH ASSESSMENT OF COMPOSITE STRUCTURES

---

10598 0B	<b>Study of CFRP adhesive bonds influenced by manufacturing-related contaminations [10598-10]</b>
10598 0C	<b>Study of CFRP adhesive bonds influenced by factors encountered during aircraft operations [10598-11]</b>
10598 0D	<b>Damage severity assessment in composite structures using ultrasonic guided waves with chirp excitation [10598-12]</b>
10598 0F	<b>Structural health monitoring of a composite F/A-18 wing section using a sparse piezoelectric transducer array [10598-14]</b>
10598 0G	<b>Study of disbond effects in a jointed composite structure under variable ambient temperatures [10598-15]</b>

10598 OH	<b>A planar array capacitive imaging system for detecting damage in composite structures: a numerical study</b> [10598-16]
10598 OI	<b>Strain monitoring using distributed fiber optic sensors embedded in carbon fiber composites</b> [10598-17]

---

#### VISION-BASED STRUCTURAL HEALTH MONITORING I

---

10598 OJ	<b>Video-based crack detection using deep learning and Nave Bayes data fusion</b> [10598-18]
10598 OK	<b>Machine learning and digital image processing for non-contact modal parameters identification of structures</b> [10598-19]
10598 OL	<b>Vision-based concrete crack detection technique using cascade features</b> [10598-21]
10598 ON	<b>Development of a flexible capacitive sensor for concrete structure health monitoring</b> [10598-156]

---

#### WIRELESS SENSORS AND APPLICATIONS I

---

10598 OP	<b>Design and validation of a wireless distributed control experimental system on three-layer spring steel structure model</b> [10598-23]
10598 OQ	<b>Dense capacitive sensor array for monitoring distortion-induced fatigue cracks in steel bridges</b> [10598-24]
10598 OR	<b>Multifunctional self-powered hydraulic system sensor node</b> [10598-25]
10598 OS	<b>Capacitance-based wireless strain sensor development</b> [10598-26]

---

#### VISION-BASED STRUCTURAL HEALTH MONITORING II

---

10598 OT	<b>Deep faster R-CNN-based automated detection and localization of multiple types of damage</b> [10598-27]
10598 OU	<b>An image-based feature tracking approach for bolt loosening detection in steel connections</b> [10598-28]
10598 OV	<b>Automated fatigue crack identification through motion tracking in a video stream</b> [10598-29]
10598 OW	<b>Automated volumetric damage detection and quantification using region-based convolution neural networks and an inexpensive depth camera</b> [10598-30]

---

## WIRELESS SENSORS AND APPLICATIONS II

---

- 10598 0X     **A methodology for structural health diagnosis and assessment using machine learning with noisy and incomplete data from self-powered wireless sensors** [10598-31]
- 10598 0Y     **A compact, low-cost, real-time interrogation system for dynamic interrogation of microstrip patch antenna sensor** [10598-32]
- 10598 0Z     **Demand-based wireless smart sensors for earthquake monitoring of civil infrastructure** [10598-33]
- 10598 10     **Piezoelectric charging and wireless communication** [10598-34]

---

## DEEP LEARNING FOR STRUCTURAL HEALTH MONITORING

---

- 10598 11     **Diagnosis of crack damage on structures based on image processing techniques and R-CNN using unmanned aerial vehicle (UAV)** [10598-35]
- 10598 12     **Deep learning-based concrete crack detection using hybrid images** [10598-36]
- 10598 13     **Deep learning-based rapid inspection of concrete structures** [10598-37]
- 10598 14     **Data-driven structural diagnosis and conditional assessment: from shallow to deep learning** [10598-38]

---

## NOVEL SENSING TECHNOLOGIES I

---

- 10598 18     **Micromechanical broadband infrared sensors based on piezoelectric bending resonators** [10598-42]
- 10598 1B     **Monolithic linear and angular sensors for real-time low-frequency structural distributed monitoring** [10598-45]
- 10598 1C     **Thick-film resistors on glass ceramic substrates as smart strain sensing aggregates for SHM** [10598-46]
- 10598 1D     **A rotational actuator based on the piezoelectric bimorph** [10598-47]
- 10598 1E     **Saliva biomarker detection using an aptamer-based nanosensor** [10598-48]

---

## NOVEL SENSING TECHNOLOGIES II

---

- 10598 1F     **Piezoelectric torsional actuation in  $d_{36}$  shear-mode PMN-PT single crystals** [10598-50]

10598 1G	<b>Sensor optimization using an evolutionary strategy for structural health monitoring in high temperature environments [10598-51]</b>
10598 1H	<b>Response of long-gauge strain sensors in proximity of force application point [10598-52]</b>
10598 1I	<b>An approach to manipulate frequency selectivity in Basilar metamembrane based broadband frequency sensors [10598-53]</b>

---

#### **MACHINE LEARNING FOR STRUCTURAL HEALTH MONITORING**

---

10598 1J	<b>Automated damage-sensitive feature extraction using unsupervised convolutional neural networks [10598-54]</b>
10598 1K	<b>Crack identification inside on-site steel box girder based on fusion convolutional neural network [10598-55]</b>
10598 1L	<b>Online fatigue crack quantification and prognosis using nonlinear ultrasonic modulation and artificial neural network [10598-56]</b>
10598 1M	<b>Automated air-coupled impact echo based non-destructive testing using machine learning [10598-57]</b>

---

#### **MODELING OF SMART MATERIALS AND SENSOR PERFORMANCE**

---

10598 1N	<b>Sensing and control of flexible hydrodynamic lifting bodies in multiphase flows [10598-59]</b>
10598 1O	<b>Self-sensing characteristics experiment of modified magneto-rheological rubber bearing [10598-61]</b>
10598 1P	<b>Fluid-structure coupled acoustic analysis of vibrating Basilar membrane within the cochlea of inner ears [10598-62]</b>

---

#### **CIVIL INFRASTRUCTURE MONITORING I**

---

10598 1Q	<b>Real-time evaluation research of pedestrian-induced footbridge vibration comfort based on smart mobile device [10598-63]</b>
10598 1R	<b>Identification of large-scale systems with noisy data using an iterated cubature unscented Kalman filter [10598-64]</b>
10598 1T	<b>Strain monitoring in masonry structures using smart bricks [10598-66]</b>

---

#### INTERROGATION OF STRUCTURES I

---

10598 1U	<b>Control of equipment isolation system using wavelet-based decentralized sliding mode control</b> [10598-67]
10598 1V	<b>Damage prognosis of China ancient wooden buildings based on structural health monitoring system</b> [10598-68]
10598 1W	<b>Discussion of using SSI-COV, refined FDD and multivariate AR model for operational modal analysis</b> [10598-69]
10598 1X	<b>Heterogeneous data fusion for impact force identification in truss structures</b> [10598-70]
10598 1Y	<b>Discussion of signal decomposition techniques on feature extraction from structural dynamic response data</b> [10598-71]
10598 2I	<b>Detection of the onset of delamination in a post-tensioned curved concrete structure using hidden Markov modeling of acoustic emissions</b> [10598-74]

### Part Two

---

#### CIVIL INFRASTRUCTURE MONITORING II

---

10598 23	<b>Telemetry techniques for continuous monitoring of partially submerged large civil infrastructure</b> [10598-76]
10598 25	<b>Vibration monitoring of a tall building applying DBF based imaging radar: VirA</b> [10598-78]
10598 26	<b>Flood fragility analysis of instream bridges</b> [10598-79]
10598 27	<b>Input and state estimation for earthquake-excited building structures using acceleration measurements</b> [10598-80]
10598 28	<b>Modal property difference formulations and optimization algorithm comparison towards FE model updating</b> [10598-81]
10598 29	<b>Seismic damage assessment of a base-isolated bridge using recursive subspace identification algorithm</b> [10598-82]

---

#### FIBER OPTIC SENSORS FOR STRUCTURAL HEALTH MONITORING I

---

10598 2A	<b>In-pavement fiber Bragg grating sensor for vehicle speed and wheelbase estimation</b> [10598-84]
10598 2D	<b>Response of an embedded distributed optical fiber sensor to directed energy and applied strain</b> [10598-87]
10598 2E	<b>A distributed optical fiber sensing system for data center thermal monitoring</b> [10598-88]

- 10598 2F      **Research on subsea pipeline scour monitoring using distributed Raman optical sensing technique** [10598-89]

---

#### NOVEL SENSING TECHNOLOGIES III

---

- 10598 2I      **Bottom-up crack detection in concrete pavements using in-pavement strain sensors** [10598-93]
- 10598 2J      **Monitoring solid metal structures with a nervous system embedded with ultrasonic 3D printing** [10598-94]
- 10598 2K      **Grating based high-frequency ultrasonic sensors** [10598-95]

---

#### SENSOR DEVELOPMENT AND APPLICATIONS

---

- 10598 2L      **Comparison of attitude and heading reference systems using foot mounted MIMU sensor data: basic, Madgwick, and Mahony** [10598-96]
- 10598 2M      **Real-time in-chip phase noise characterization of digitally controlled swept laser source** [10598-97]

---

#### NEW TECHNOLOGICAL ADVANCES

---

- 10598 2Q      **Design of smart harvester for capturing energy from human ankle dorsiflexion to reduce user effort** [10598-101]
- 10598 2R      **The effects of damage accumulation in optimizing a piezoelectric energy harvester configuration** [10598-102]
- 10598 2S      **Accoustoelastic MetaWall as industrial noise barriers with simultaneous energy harvesting capability** [10598-103]
- 10598 2T      **Output analysis of swarm of neural oscillators stimulated by earthquake-induced acceleration responses of a structure** [10598-104]
- 10598 2U      **Smart cements: repairs and sensors for concrete assets** [10598-105]

---

#### INTEGRATION OF SMART SENSING SYSTEMS

---

- 10598 2W      **Auto-Gopher-II: a wireline rotary-hammer ultrasonic drill that operates autonomously** [10598-107]
- 10598 2X      **System identification and vibration-based damage detection in a concrete shear wall system** [10598-109]



---

#### INTERROGATION OF STRUCTURES II

---

- 10598 2Y      **Determination of wave velocity for source location of a granite specimen** [10598-110]
- 10598 2Z      **A study on the detection of compressed micro-crack by nonlinear wave modulation technique** [10598-111]
- 10598 30      **3D printed origami as a realization of analysis-driven morphing structures** [10598-112]
- 10598 31      **Variability analysis of asphalt mixture beam bending test** [10598-113]
- 10598 32      **Updating the finite element model for electrical impedance tomography using self-organizing map** [10598-114]

---

#### FIBER OPTIC SENSORS FOR STRUCTURAL HEALTH MONITORING II

---

- 10598 33      **Real time corrosion detection of rebar using embeddable fiber optic ultrasound sensor** [10598-115]
- 10598 35      **Monitoring of soil nailed slope stabilizations using distributed fiber optic sensing** [10598-117]
- 10598 36      **Pipeline internal corrosion sensor based on fiber optics and permanent magnets** [10598-118]
- 10598 37      **The development of a fiber Bragg grating based smart washer** [10598-119]
- 10598 38      **Effect of continuous optical fiber bonding on ultrasonic detection using fiber Bragg grating** [10598-120]
- 10598 39      **Damage detection at web/flange junction of welded I-section steel beam based on impact-optic technique** [10598-121]
- 10598 3A      **A three-dimensional sliding and debonding sensor based on triaxial optical fiber Fabry-Perot interferometers** [10598-122]

---

#### INTERNET OF THINGS SENSOR NETWORK

---

- 10598 3B      **Crack detection in RC structural components using a collaborative data fusion approach based on smart concrete and large-area sensors** [10598-123]
- 10598 3D      **Road sensor network for smart city application** [10598-125]
- 10598 3E      **Real-time signal processing for sub-THz range grating-based distributed fiber sensing** [10598-126]

- 10598 3F **Surrogate model for condition assessment of structures using a dense sensor network** [10598-127]
- 10598 3H **Sparse sensor networks for active structural health monitoring using highly integrated CMOS transceivers** [10598-129]

---

#### POSTER SESSION

---

- 10598 3I **Simulation of strain dependent damping in SMA embedded hybrid beams** [10598-130]
- 10598 3J **An optical fiber extrinsic Fabry-Perot interferometer based displacement sensor with centimeter measurement range** [10598-131]
- 10598 3K **Comparison of binary and multi-level logic processing for an optical encoder** [10598-132]
- 10598 3L **A high-linear sweep laser source to interrogate sub-terahertz range fiber sensors for dynamic strain sensing applications** [10598-133]
- 10598 3M **Design of a new inside multi-coils clutch for knee-exoskeleton structure based on Helmholtz phenomenon and magneto-rheological fluid** [10598-134]
- 10598 3N **Design of a new exoskeleton based on the combination of two magneto-rheological damper** [10598-135]
- 10598 3O **Wide-range displacement sensor based on a hollow coaxial cable Fabry-Perot resonator** [10598-136]
- 10598 3P **Buckled beam based optical interferometric pressure sensor with low temperature cross-sensitivity** [10598-137]
- 10598 3Q **Numerical study of cornea appplanation by using a portable force-displacement sensor for intraocular pressure measurements** [10598-138]
- 10598 3R **Design and realization of data loss compensation system based on compressed sensing** [10598-139]
- 10598 3S **Design and verification of an indoor wireless UWB positioning system for civil structures** [10598-140]
- 10598 3T **Inertial monolithic sensors for low frequency acceleration measurement of spacecrafts and satellites** [10598-141]
- 10598 3V **Convolutional neural networks-based crack detection for real concrete surface** [10598-143]
- 10598 42 **Principle of a test bench for simulation of vehicular braking of 1/4 vehicle** [10598-150]
- 10598 44 **Optimal sensor placement for continuous optical fiber sensors** [10598-152]

- 10598 46      **Integrating 3D scanning within a simulation framework for structural mechanics** [10598-154]
- 10598 49      **Finite element analysis of RC beam strengthened with FOS embedded carbon fiber sheet**  
[10598-158]
- 10598 4A      **Experimental investigation on the FOS embedded carbon fiber sheet for bridge sensing and  
reinforcement** [10598-159]