

ISSN 1726-5749

SENSORS & TRANSDUCERS

2<sup>vol. 10
Special</sup>
/11



Sensor Device Technologies and Applications

International Frequency Sensor Association Publishing





Sensors & Transducers

Volume 10, Special Issue,
February 2011

www.sensorsportal.com

ISSN 1726-5479

Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, fax: +34 93 4011989, e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific

Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

- Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Northern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygtantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayeshe, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Motors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachiba, Chellali, Université de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerde Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, N.I. Center for Higher Education, (N.I. University), India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Université de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevic, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Intersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ. of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politécnica de Madrid, Spain
Homencovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khelfaoui, Rachid, Université de Bechar, Algeria
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South
Ko, Sang Choon, Electronics. and Telecom. Research Inst., Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India

Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukasiewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Nabok, Aleksey, Sheffield Hallam University, UK
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Seteбал, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S., National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politècnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politécnica de Cataluña, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shah, Kriyang, La Trobe University, Australia
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Seif, Selemanni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., NanoSonix Inc., USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thirunavukkarasu, I., Manipal University Karnataka, India
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vanga, Raghav Rao, Summit Technology Services, Inc., USA
Vaseashta, Ashok, Marshall University, USA
Vazquez, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Pacific Northwest National Laboratory, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung Univ. of Science and Technology, Taiwan
Wu, ZhaoYang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Sen, Drexel University, USA
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Shuang-Hua, Loughborough University, UK
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufra Garcia, Alberto, Seville University, Spain
Zakaria, Zulkarnay, University Malaysia Perlis, Malaysia
Zagnoni, Michele, University of Southampton, UK
Zamani, Cyrus, Universitat de Barcelona, Spain
Zeni, Luigi, Second University of Naples, Italy
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhang, Xueji, World Precision Instruments, Inc., USA
Zhong, Haoxiang, Henan Normal University, China
Zhu, Qing, Fujifilm Dimatix, Inc., USA
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 10
Special Issue
February 2011

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Foreword

Sergey Y. Yurish, Petre Dini I

Film-based Sensors with Piezoresistive Molecular Conductors as Active Components: Strain Damage and Thermal Regeneration

Elena Laukhina, Raphael Pfattner, Marta Mas-Torrent, Concepció Rovira, Jaume Veciana, Vladimir Laukhin 1

Intelligent Sensor for Non-destructive Tests Applications

Irinela Chilibon 13

Sensor Devices with Metrological Self-Check

Roald Taymanov, Ksenia Sapozhnikova, Igor Druzhinin 30

A Simple and Universal Resistive-Bridge Sensors Interface

Sergey Y. Yurish 46

Charge-sensitive Infrared Phototransistors: Single-photon Detectors in the Long-Wavelength Infrared

Takeji Ueda and Susumu Komiyama 60

In the Field Application of a New Sensor for Monitoring Road and Runway Surfaces

Amedeo Troiano, Eros Pasero, Luca Mesin 71

A New Concept for an Effective Leak Detection and Localisation in Multiphase Fluid Pipelines

Mahmoud Meribout 84

Double Pin Photodiodes with Two Optical Gate Connections for Light Triggering: A Capacitive Two-phototransistor Model

Manuel A. Vieira, Manuela Vieira, João Costa, Paula Louro, Miguel Fernandes, A. Fantoni 96

Methane Detection by Nano ZnO Based MIM Sensor Devices

P. Bhattacharyya, P. K. Basu, S. Basu 121

Detection of Hydrogen by Noble Metal Treated Nanoporous Si and ZnO Thin Films

Jayita Kanungo, Palash Kumar Basu, Anita Lloyd Spetz, Sukumar Basu 131

Fabrication and Characterization of Ethanol Sensor Based on RF Sputtered ITO Films

H. J. Pandya, Sudhir Chandra and A. L. Vyas 141

Performances of Three Miniature Bio-inspired Optic Flow Sensors under Natural Conditions

Stéphane Viollet, Franck Ruffier, Thomas Ray, Lubin Kerhuel, Fabrice Aubépart, Nicolas Franceschini, Mohsine Ménouni 151

Generation of HDL Models for Bio-Impedance Sensor Simulation based on Microelectrodes <i>Alberto Yúfera, Estefanía Gallego.....</i>	160
Design of Networked Low-Cost Wireless Noise Measurement Sensor <i>Ilkka Kivelä, Chao Gao, Jari Luomala, Jukka Ihalainen, Ismo Hakala.....</i>	171
Fast FPGA Implementation of an Original Impedance Analyser <i>Abdulrahman Hamed, Etienne Tisserand, Yves Berviller, Patrick Schweitzer</i>	191
Experimental and Computational Performance Analysis of a Multi-Sensor Wireless Network System for Hurricane Monitoring <i>Chelakara Subramanian, Gabriel Lapilli, Frederic Kreit, Jean-Paul Pinelli, Ivica Kostanic.....</i>	206


Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm>

International Frequency Sensor Association (IFSA).

Call for Books Proposals

Sensors, MEMS, Measuring instrumentation, etc.

International Frequency Sensor Association Publishing



IFSA
www.sensorsportal.com

Benefits and rewards of being an IFSA author:


1) Royalties.
Today IFSA offers most high royalty in the world: you will receive 50 % of each book sold in comparison with 8-11 % from other publishers, and get payment on monthly basis compared with other publishers' yearly basis.

2) Quick Publication.
IFSA recognizes the value to our customers of timely information, so we produce your book quickly: 2 months publishing schedule compared with other publishers' 5-18-month schedule.

3) The Best Targeted Marketing and Promotion.
As a leading online publisher in sensors related fields, IFSA and its Sensors Web Portal has a great expertise and experience to market and promote your book worldwide. An extensive marketing plan will be developed for each new book, including intensive promotions in IFSA's media: journal, magazine, newsletter and online bookstore at Sensors Web Portal.

4) Published Format: pdf (Acrobat).
When you publish with IFSA your book will never go out of print and can be delivered to customers in a few minutes.

You are invited kindly to share in the benefits of being an IFSA author and to submit your book proposal or/and a sample chapter for review by e-mail to editor@sensorsportal.com These proposals may include technical references, application engineering handbooks, monographs, guides and textbooks. Also edited survey books, state-of-the art or state-of-the-technology, are of interest to us.





The Second International Conference
on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- Sensor device technologies
- Sensors signal conditioning and interfacing circuits
- Medical devices and sensors applications
- Sensors domain-oriented devices, technologies, and applications
- Sensor-based localization and tracking technologies

<http://www.iaria.org/conferences2011/SENSORDEVICES11.html>



The Fifth International Conference on Sensor
Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- APASN: Architectures, protocols and algorithms of sensor networks
- MECSN: Energy, management and control of sensor networks
- RASQOFT: Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSED: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

<http://www.iaria.org/conferences2011/SENSORCOMM11.html>



The Fourth International Conference on Advances
in Circuits, Electronics and Micro-electronics

CENICS 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Semiconductors and applications
- Design, models and languages
- Signal processing circuits
- Arithmetic computational circuits
- Microelectronics
- Electronics technologies
- Special circuits
- Consumer electronics
- Application-oriented electronics

<http://www.iaria.org/conferences2011/CENICS11.html>



Performances of Three Miniature Bio-inspired Optic Flow Sensors under Natural Conditions

¹Stéphane Viollet, ¹Franck Ruffier, ¹Thomas Ray, ¹Lubin Kerhuel,
¹Fabrice Aubépart, ¹Nicolas Franceschini, ²Mohsine Ménouni

¹Institute of Movement Sciences - Biorobotics - CP938 - 163 av Luminy F-13288 Marseille, France

²Center for Particle Physics (CPPM) - CP902 - 163 av Luminy F-13288 Marseille, France

Received: 29 October 2010 / Accepted: 11 January 2011 / Published: 8 February 2011

Abstract: Considerable attention has been paid during the last decade to vision-based navigation systems based on optic flow (OF) cues. OF-based systems have been implemented on an increasingly large number of sighted autonomous robotic platforms. Nowadays, the OF is measured using conventional cameras, custom-made sensors and even optical mouse chips. However, very few studies have dealt so far with the reliability of these OF sensors in terms of their precision, range and sensitivity to illuminance variations. Three miniature custom-made OF sensors developed at our laboratory, which were composed of photosensors connected to an OF processing unit were tested and compared in this study, focusing on their responses and characteristics in real indoor and outdoor environments in a large range of illuminance. It was concluded that by combining a custom-made aVLSI retina equipped with Adaptive Pixels for Insect-based Sensor (APIS) with a bio-inspired visual processing system, it is possible to obtain highly effective miniature sensors for measuring the OF under real environmental conditions. *Copyright © 2011 IFSA.*

Keywords: Bio-inspired optic flow sensor, vision-based navigation system, autonomous robotic platform, OF sensor, VLSI retina, bio-inspired visual processing system

1. Introduction

Several examples of embedded optic flow-based navigation systems have been developed during the last decade or so. As in their natural counterparts (flies, bees, etc.) where the optic flow (OF) provides vital cues, aerial robots are now being endowed with similar means of detecting and processing OF for obstacle avoidance purposes [1] [2] [3] [4], terrain following and landing [5] and wall following [6]. However, there exist very few robotic examples in which OF sensing has been successfully

implemented under real indoor [7] or outdoor conditions environment [8] [9] [4]. Many OF sensors have been developed using analog VLSI technology (e.g., [10] [11]), but their relatively complex and bulky peripheral electronics have often made it impossible to implement these aVLSI sensors onboard aerial robots. The authors of some recent studies mounted off-the-shelf mouse sensors onboard terrestrial [12] [13] and aerial robotic platforms [9] [4]. However, the performances of these systems in terms of their resolution, accuracy, invariance to illuminance and contrast have not been properly assessed so far, except in [4] where a static characteristic of a mouse sensor for OF measurement is given. In this study, it was therefore proposed to compare the output signals of three custom-made bio-inspired OF sensors with a reference angular speed measured by a rate gyro. Our own OF sensors, which we have also called Elementary Motion Detectors (EMDs), process the OF by comparing the signals collected by adjacent photosensors [14][15][2]. A purely *rotational* optic flow was generated by rotating the various OF sensors placed in front of a natural indoor or outdoor scene while the reference angular speed was being recorded synchronously. By definition, the rotational optic flow is not affected by the distance to object. A description of the various OF sensors tested here is given in section II. Section III gives an account of the performance of these OF sensors placed in a real environment in a large range of illuminance.

2. Description of the OF Sensors

Our OF sensors are basically composed of a lens and two photosensors (photodiodes) placed behind the lens. Each photodiode's output signal is sent to an OF processing unit where a discrete version of an EMD circuit is running. An EMD is used here to assess the relative angular speed Ω of contrasting features in the environment (i.e., the optic flow). Our original EMD design [14][15][2] consists of an analog circuit producing an output signal that increases as the time lag Δt between its two inputs decreases. The output signal therefore increases with the angular speed Ω , i.e., with the OF. Like the fly's motion-detecting neurons from which it was originally inspired [16], our electronic analogue EMD reacts to both dark-to-light (ON) and light-to-dark (OFF) contrast transitions. The EMD-inspired signal processing steps implemented onboard the three OF sensors can be decomposed into 5 steps as follows:

- Step 1: Low-pass spatial filtering (which is achieved by defocusing the lens to obtain Gaussian blurring),
- Step 2: Band-pass temporal filtering to derivate the visual signals and to reduce the noise and interference (such as the 100-Hz interference originating from artificial lighting),
- Step 3: Thresholding for contrast detection,
- Step 4: Measuring the time lag Δt (travel time) between the thresholded signals,
- Step 5: Computing the OF by applying :

$$\Omega_{meas} = \frac{\Delta\varphi}{\Delta t} \quad (1)$$

The angles $\Delta\varphi$ and $\Delta\rho$, called interreceptor angle and acceptance angle, respectively, are adjusted by slightly defocusing the lens placed in front of the photodiodes. For each OF sensor, the angle $\Delta\rho$ determines directly the cut-off frequency of the low-pass spatial filtering (step 1) whereas the angle $\Delta\varphi$ determines the measurement range of the OF Ω . For a given resolution (here 1ms) in the measurement of the time lag Δt , the smaller the angle $\Delta\varphi$, the smaller the OF range will be. In this study, three OF sensors based on the same principle but using different technologies were compared (see Fig. 1).

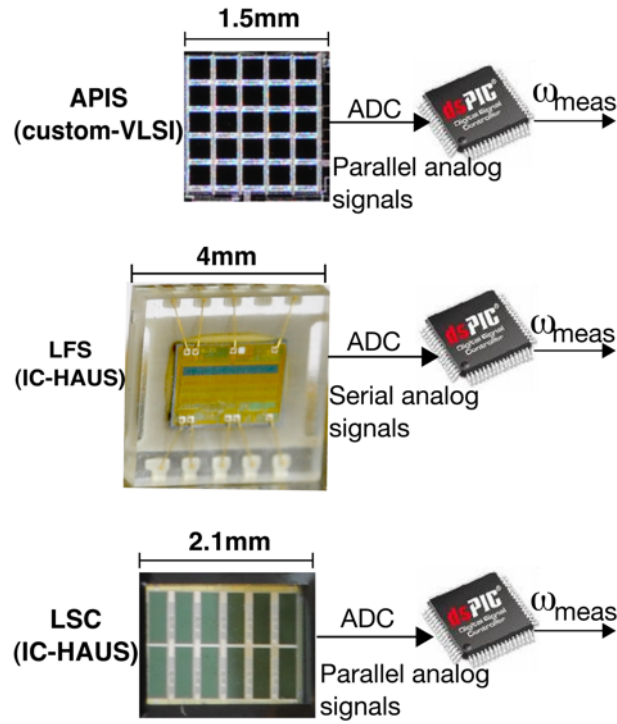


Fig. 1. General hardware architecture of the three OF sensors composed of a photodiodes array connected, via an analog-to-digital converter (ADC), to an external optic flow (OF) processing unit. The custom-made Adaptive Pixels for Insect-based Sensors (APIS) is made of 5x5 Delbrück-type [17] adaptive sensors. The off-the-shelf linear array (LFS and LSC from IC-HAUS) integrate amplifier circuits at the pixel level. For each sensor, the optic flow Ω_{meas} measured by each sensor is computed from the visual input signals provided by two adjacent pixels.

The first OF sensor, called APIS (Adaptive Pixels for Insect-based Sensor), is composed of a single lens (focal length 6.5mm) placed in front of a VLSI retina made of 2 adaptive pixels [17]. This retina was developed in collaboration with the Center for Particle Physics (CPPM, Marseille, France) [18]. The second OF sensor, called LSC, is composed of an optical assembly mounted onto an off-the-shelf photodiode array consisting of 6 pixels (IC-Haus, LSC). The LSC sensor was also endowed with an Automatic Gain Control (AGC) function implemented onboard the microcontroller. The third OF sensor, called LFS, is also composed of an optical assembly mounted in front of a 32 pixels linear imager (IC-Haus, LFS). The optic assemblies of the LSC and LFS sensors were simply borrowed from a low cost miniature camera (Velleman, focal length 4.9 mm) and a tiny CMOS color camera (CONRAD, focal length 2.2 mm), respectively. We used three different optics to make the ratio $\Delta\phi/\Delta\rho$ equal to 1. This ratio can be also found in several insects [19]. Table 1 summarizes the main characteristics of the OF sensors.

Table 1. Main characteristics of the OF sensors.

	APIS	LFS	LSC
Photodiode size (μm)	250×250	65×65	300×1600
Pixel pitch (μm)	300	63.5	420
F_{number}	1.1	1.4	2.8
Focal length (mm)	6.5	2.2	4.9
$\Delta\rho(^{\circ})$	3.41	0.83	7
$\Delta\varphi(^{\circ})$	3.2	0.83	7.3

Fig. 2 shows the three OF sensors mounted on a common printed circuit board. An additional illuminance sensor was connected to an analog amplifier running in the photovoltaic mode. The photocurrent I_{ph} of this illuminance sensor is obtained as follows [20]:

$$I_{ph} = \left(e^{\frac{V_{out}}{0.25}} - 1 \right) I_{dark} , \quad (2)$$

where the dark current I_{dark} is equal to 1nA and V_{out} is the amplifier's output voltage.

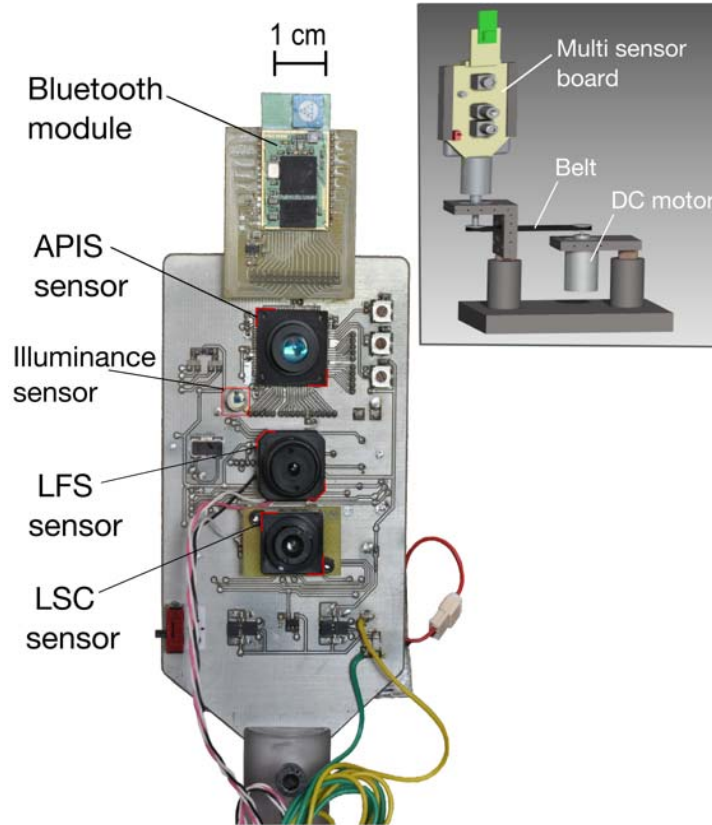


Fig. 2. The multi sensor PCB board includes three OF sensors, an illuminance sensor based on a single photodiode, a rate gyro for measuring the reference angular speed (i.e., the rotational speed of the board) and a microcontroller (dSpic). The microcontroller processes the visual signals of all the three OF sensors at a sampling frequency of 1 kHz. The measured OF Ω_{meas} and the measured rotational speed Ω_{gyro} are recorded synchronously and sent to a computer through a Bluetooth module. The wireless link and the small onboard battery (LiPo, 300 mAh-3.3 V) made the multi sensor board free to rotate in complete autonomy on its two miniature ball-bearings. (Top right) A rotational speed was imposed on the board by means of a DC servomotor.

3. Experimental Results

As discussed in Section II, an optic flow sensor is an optical device that measures an angular speed Ω_{meas} . The three OF sensors were tested in indoor and outdoor environments (see Fig. 3) by comparing their output signals with respect to the angular speed Ω_{gyro} measured by a MEMS rate gyro with a maximum speed range of 300°/s. As shown in Fig. 2 (top right), the multi sensor board was coupled to a DC motor via a belt, which made it possible for the experimenter to adjust the rotational speed of the

board. The board was made to rotate at a rotational speed Ω varying sinusoidally within 60°/s to 300°/s range in the case of the APIS and LSC sensors and within the 60°/s to 200°/s range in that of the LFS sensor.



Fig. 3. Panoramic view of the real indoor (top) and outdoor (bottom) environments that were used to assess the OF sensor's responses.

3.1. Indoor Optic Flow Measurement

The response of the three OF sensors placed in the indoor environment is shown in Fig. 4. The measured optic flow Ω_{meas} (dark points) is superimposed on the measured reference angular speed Ω_{gyro} . Despite the strong 30-fold attenuated illuminance, the responses of the APIS and LSC sensors faithfully reflected the sinusoidal variation imposed by the mechanical rotation of the board. The response of the LFS was found to be noisier at high and very low illuminance levels due to the saturation of its output voltage and its lower sensitivity at the pixel level, respectively. The APIS and the LSC sensors were therefore selected for conducting further tests outdoors and for measuring their static characteristics.

3.2. Outdoor Optic Flow Measurement

Fig. 5 gives the responses of the two OF sensors placed in the outdoor environment. Although the illuminance was about 10-fold greater than the highest value of I_{ph} in the indoor environment, the dynamic outdoor responses of both the APIS and the LSC sensors followed the sinusoidal variations in the angular speed. The fact that a larger number of matching errors were observed in the case of the APIS sensor suggests that the specific optics used here (with a relatively large *f-number* of 1.1) was less well suited to the task in question than that of the LSC sensor (*f-number* of 2.8).

3.3. Static Characteristics of the OF Sensors

As shown in Fig. 6, the APIS sensor showed a high level of invariance to the illuminance while linearity of its static characteristics was well maintained. The static characteristics of the LSC sensor also showed a good linearity and a good invariance to the lighting conditions, provided the illuminance was maintained at a relatively high level.

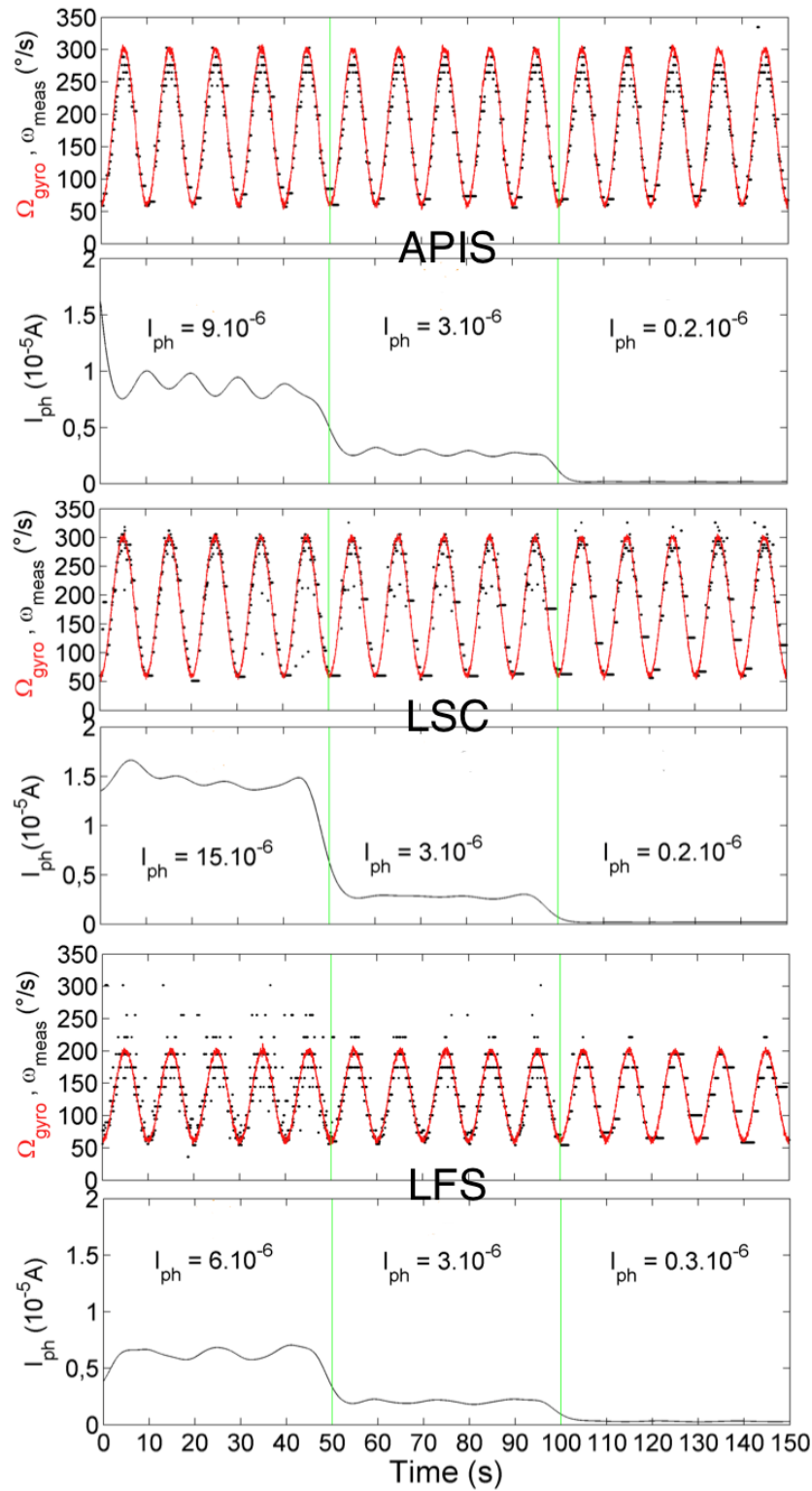


Fig. 4. Response profile of the three OF sensors to a sinusoidally changing rotational speed of the board on which they are mounted (cf. Fig. 2). The three OF sensors were placed in the *indoor* environment (Fig. 3) under three different lighting conditions. During the experiment, the mean value of the photodiode's current I_{ph} , i.e., the current measured by the illuminance sensor (red continuous line) was reduced stepwise over a range of up to 30-fold. Unlike the LFS sensor, the LSC with its AGC (cf. text) and the APIS sensor with its adaptive pixels showed a remarkable insensitivity to the illuminance.

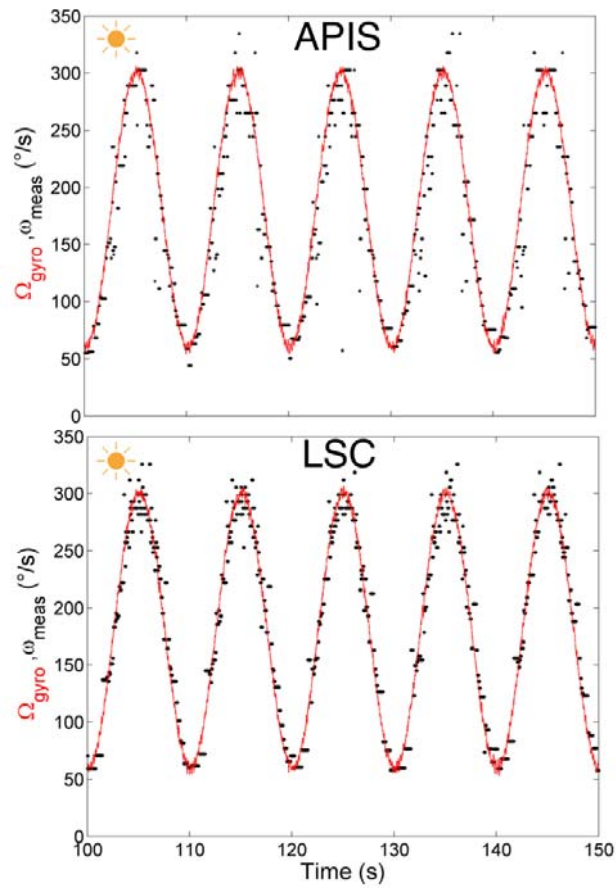


Fig. 5. Response of the LSC with its AGC and APIS sensors placed in the *outdoor* environment (Fig. 3). Despite the strong illuminance (which was 10 times higher than the maximum value of I_{ph} in the indoor environment), the two OF sensors faithfully followed the sine variation of the rotational angular speed.

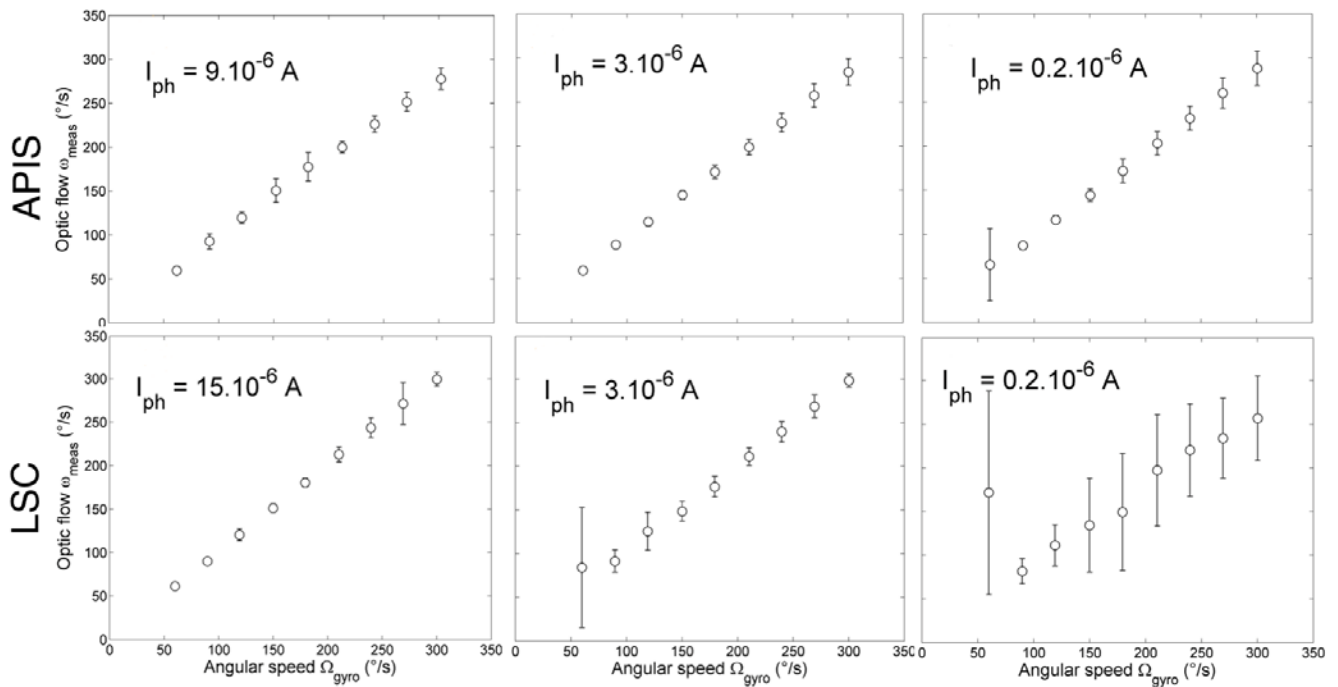


Fig. 6. Static characteristics of the LSC with its AGC and APIS sensors assessed by varying the rotational speed from 60°/s to 300°/s in 30°/s-steps. The different values of the average photocurrent I_{ph} given in this figure indicate that the illuminance of the indoor environment was attenuated by 30 dB.

4. Conclusion

Three OF sensors were tested here in real indoor and outdoor environments and under various lighting conditions. It turned out from the results of these tests that the APIS sensor based on a custom aVLSI retina equipped with adaptive pixels gave the best features in terms of invariance to the illuminance and precision. However, under outdoor conditions, the LSC sensor with its AGC made fewer matching errors (OF measurement errors) probably thanks to its better suited optics (smaller optical aperture, larger f -number). We therefore intend to modify the APIS optics to improve this sensor's dynamic responses in outdoor environments. To summarize, it was established here that OF sensors consisting of low cost optics and classical electronic components combined with appropriate visual signal processing methods can give accurate and reliable results under *natural conditions* (indoor or outdoor environments). This study brings us one step further towards implementing tiny, light and robust OF sensors that could invest many application fields as domestic, biomedical, automotive, robotic and aerospace sensors.

Acknowledgements

We are very grateful to M. Boyron for his involvement in the electronic design and to Y. Luparini. This work was supported by the French Defense Agency (DGA, 05 34 022), the National Research Agency (ANR RETINAE and EVA projects) and the European Commission via the CURVACE project. The project CURVACE acknowledges the financial support of the Future and Emerging Technologies (FET) program within the Seventh Framework Program for Research of the European Commission, under FET Open grant number: 237940.

References

- [1]. W. E. Green et P. Y. Oh, Optic-Flow-Based Collision Avoidance, *Robotics & Automation Magazine, IEEE*, Vol. 15, No. 1, Mar. 2008, pp. 96-103.
- [2]. N. Franceschini, F. Ruffier, J. Serres, et S. Viollet, Aerial vehicles, T. M. Lam, Éd. Vienna: *In-Tech*, 2009, pp. 747-770.
- [3]. M. Srinivasan, S. Thirrowgood, et D. Soccol, Competent vision and navigation systems, *IEEE Robotics & Automation Magazine*, Vol. 16, No. 3, Sep. 2009, pp. 59-71.
- [4]. A. Beyeler, J. Zufferey, et D. Floreano, Vision-based control of near-obstacle flight, *Autonomous Robots*, Vol. 27, No. 3, Oct. 2009, pp. 201-219.
- [5]. F. Ruffier et N. Franceschini, Optic flow regulation: the key to aircraft automatic guidance, *Robotics and Autonomous Systems*, Vol. 50, 2005, pp. 177-194.
- [6]. J. Serres, D. Dray, F. Ruffier, et N. Franceschini, A vision-based autopilot for a miniature air vehicle: joint speed control and lateral obstacle avoidance, *Autonomous Robots*, Vol. 25, No. 1, 2008, pp. 103-122.
- [7]. J. Zufferey et D. Floreano, Fly-inspired visual steering of an ultralight indoor aircraft, *IEEE Transactions on Robotics*, Vol. 22, 2006, pp. 137-146.
- [8]. M. Garratt et J. Chahl, Visual control of an autonomous Helicopter, in *Proceeding of American Institute of Aeronautics and Astronautics*, 2003.
- [9]. S. Griffiths, J. Saunders, A. Curtis, B. Barber, T. McLain, et R. Beard, Maximizing miniature aerial vehicles, *Robotics & Automation Magazine, IEEE*, Vol. 13, No. 3, Sep. 2006, pp. 34-43.
- [10]. R. R. Harrison et C. Koch, A Robust Analog VLSI Motion Sensor Based on the Visual System of the Fly, *Autonomous Robots*, Vol. 7, No. 3, Nov. 1999, pp. 211-224.
- [11]. R. Moeckel et S. Liu, Motion Detection Circuits for a Time-To-Travel Algorithm, in *Circuits and Systems, 2007. ISCAS 2007. IEEE International Symposium on*, 2007, pp. 3079-3082.
- [12]. J. D. Jackson, D. W. Callahan, et J. Marstrand, A Rationale for the use of Optical Mice Chips for Economic and Accurate Vehicle Tracking, in *Proc. of the IEEE International Conference on Automation Science and Engineering CASE 2007*, 2007, pp. 939-944.
- [13]. H. Dahmen, A. Millers, et H. A. Mallot, Flying insects and robots, D. Floreano, J. C. Zufferey,

M. V. Srinivasan, et C. P. Ellington, Éd. Springer, 2009, pp. 115-126.

- [14].C. Blanes, Appareil visuel élémentaire pour la navigation à vue d'un robot mobile autonome., Master Thesis in Neurosciences, *Univ. of Marseille*, France, 1986.
- [15].F. Ruffier, S. Viollet, S. Amic, et N. Franceschini, Bio-inspired optical flow circuits for the visual guidance of Micro-Air Vehicles, in *Proc. of the IEEE Int. Symposium on Circuits and Systems (ISCAS)*, Vol. III, 2003, pp. 846-849.
- [16].N. Franceschini, A. Riehle, et A. L. Nestour, Directionally Selective Motion Detection by Insect Neurons, in *Facets of vision*, D. G. Stavenga, R. C. Hardie, Eds., *Springer*, Berlin, 1989, pp. 360-390.
- [17].T. Delbrück et C. A. Mead, Adaptive photoreceptor with wide dynamic range, in *Proc. of the IEEE International Symposium on Circuits and Systems ISCAS '94*, Vol. 4, 1994, pp. 339-342.
- [18].F. Aubépart, M. Menouni, T. Loubignac, B. Dinkelspieler, et N. Franceschini, Capteur de flux optique basé sur une rétine intégrée et un FPGA, in *Colloque Interdisciplinaire en Instrumentation*, 2007, pp. 508-520.
- [19].M. F. Land, Visual acuity in insects., *Annu Rev Entomol*, Vol. 42, 1997, pp. 147-177.
- [20].J. D. Riggs, Notes on Silicon Photodiode Detectors, *International Amateur-Professional Photoelectric Photometry Communications*, Vol. 14, Déc. 1983, pp. 30-44.

2011 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)

CMOS Image Sensors Technologies & Markets - 2010 Report

**Disruptive technologies are paving the way
to the future of digital imaging industry !**

**IFSA offers
a SPECIAL PRICE**

Image sensors have come a long way since the first introduction of CCD sensor technology in the 1990's. They made a big jump in the 2000's with the introduction of CMOS sensor technology which gave birth to the low-cost, high volume camera phone market. Image sensors are now part of our everyday life: from cell-phone cameras, to notebook webcams, digital cameras, video camcorders to security & surveillance systems. In the future, new markets are also emerging such as sensors for medical applications, automotive security features, but also gaming and home TV webcams ... The reason why we are now releasing our first report on the CMOS image sensor industry is that we feel that we are at an historic turning point for this young, but still maturing industry.

http://www.sensorsportal.com/HTML/CMOS_Image_Sensors.htm



Uncooled Infrared Cameras and Detectors Thermography and Vision Markets 2010 – 2015

MEMS Micro-Bolometers Drive Growth

**IFSA offers
a SPECIAL PRICE**

This report provides market data on both camera and detector; IR camera supply chain levels and main technological trends for detector/microbolometer.

http://www.sensorsportal.com/HTML/Detectors_for_Thermography.htm



Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

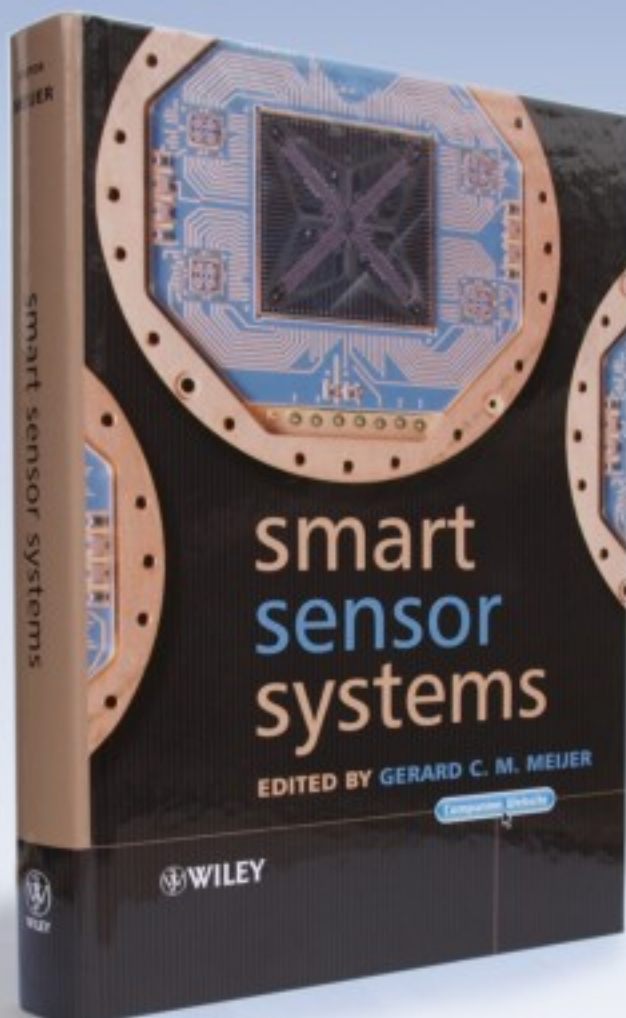
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submition.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.pdf



'Written by an internationally-recognized team of experts, this book reviews recent developments in the field of smart sensors systems, providing complete coverage of all important systems aspects. It takes a multidisciplinary approach to the understanding, design and use of smart sensor systems, their building blocks and methods of signal processing.'



Order online:

http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm

www.sensorsportal.com