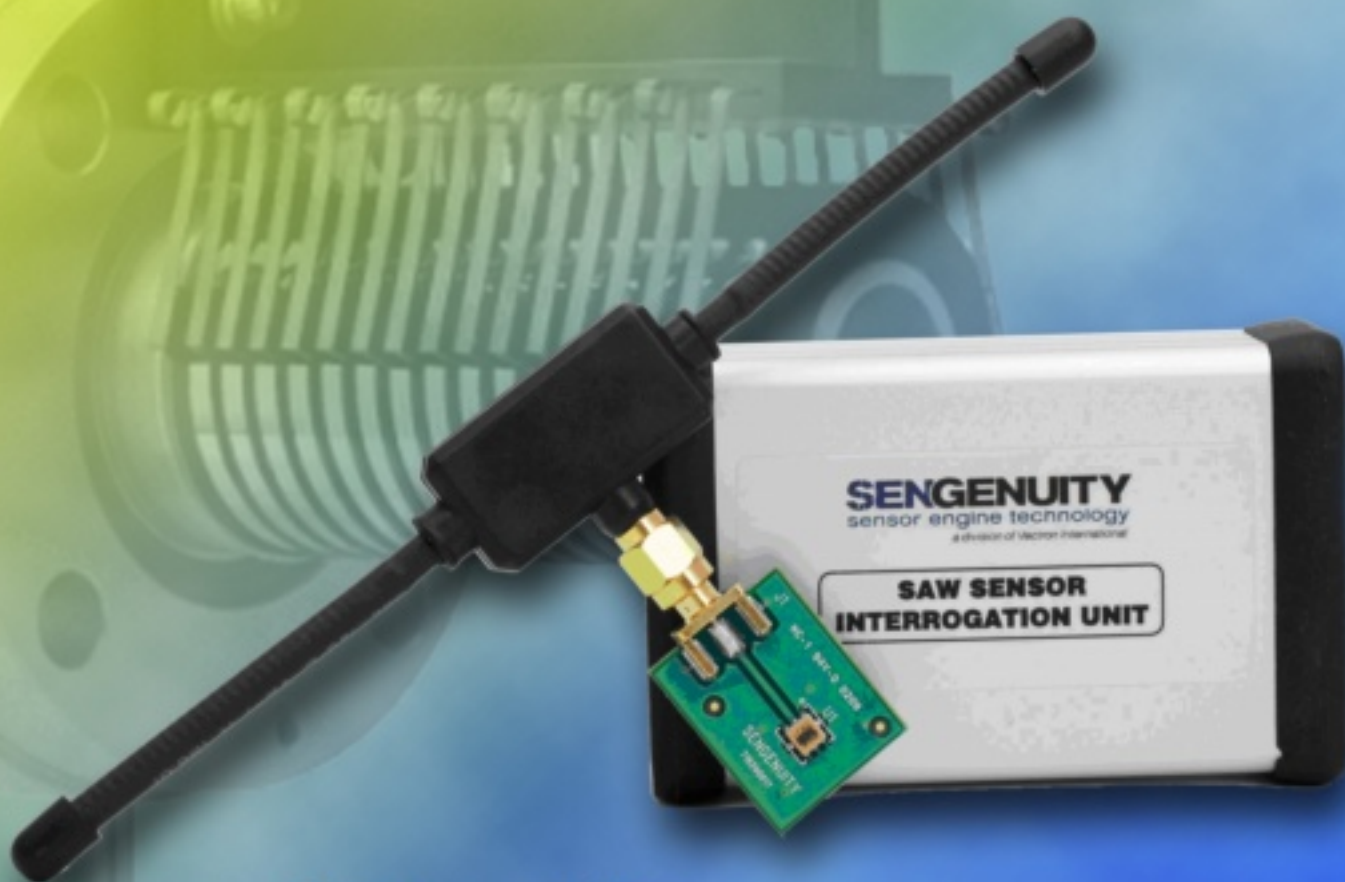


ISSN 1726-5479

# SENSORS & TRANSDUCERS

7<sup>vol. 106</sup>  
/09



## Sensor Networks and Wireless Sensor Networks

International Frequency Sensor Association Publishing





**Editor-in-Chief:** professor Sergey Y. Yurish, phone: +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  
**Ayesh, 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  
**Benachaiba, Chellali**, Universitaire 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  
**Cerda 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**, VIT University, Tamil Nadu, 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  
**Chiriack, 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**, Universite 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  
**Djordjevich, 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**, Instersema 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 Politecnica de Madrid, Spain  
**Homentcovschi, 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  
**Khan, Asif**, Aligarh Muslim University, Aligarh, India  
**Sapozhnikova, Ksenia**, D.I.Mendeleyev Institute for Metrology, Russia

**Kim, Min Young**, Kyungpook National University, Korea South  
**Ko, Sang Choon**, Electronics and Telecommunications Research Institute, 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**, Universidade NOVA de Lisboa, Portugal  
**Lorenzo, Maria Encarnacio**, Universidad Autonoma de Madrid, Spain  
**Lukaszewicz, 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  
**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 Setebal, 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  
**Raouf, 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 Catalunya, 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  
**Saxena, Vibha**, Bhabha Atomic Research Centre, Mumbai, India  
**Schneider, John K.**, Ultra-Scan Corporation, USA  
**Seif, Selemani**, Alabama A & M University, USA  
**Seifter, Achim**, Los Alamos National Laboratory, USA  
**Sengupta, Deepak**, Advance Bio-Photonics, India  
**Shearwood, Christopher**, Nanyang Technological University, Singapore  
**Shin, Kyuho**, Samsung Advanced Institute of Technology, Korea  
**Shmaliy, Yuriy**, Kharkiv National Univ. of Radio Electronics, Ukraine  
**Silva Girao, Pedro**, Technical University of Lisbon, Portugal  
**Singh, V. R.**, National Physical Laboratory, India  
**Slomovitz, Daniel**, UTE, Uruguay  
**Smith, Martin**, Open University, UK  
**Soleymannpour, 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.**, Northwestern University, USA  
**Stefan-van Staden, Raluca-Ioana**, University of Pretoria, South Africa  
**Sunriddetchka, 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  
**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  
**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**, Advanced Micro Devices, 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, Tao**, University of California, Irvine, USA  
**Yang, Dongfang**, National Research Council, Canada  
**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  
**Yufera Garcia, Alberto**, Seville University, Spain  
**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, Quintao**, 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 106  
Issue 7  
July 2009

[www.sensorsportal.com](http://www.sensorsportal.com)

ISSN 1726-5479

## Research Articles

<b>Wireless Surface Acoustic Wave Sensors</b> <i>Kerem Durdag</i> .....	1
<b>Reliability Modeling of Wireless Sensor Network for Oil and Gas Pipelines Monitoring</b> <i>Khalid El-Darymli, Faisal Khan, Mohamed H. Ahmed</i> .....	6
<b>Level Controlled Gossip Based Tsunami Warning Wireless Sensor Networks</b> <i>Santosh Bhima, Anil Gogada and Ramamurthy Garimella</i> .....	27
<b>A Distributed Approach to Area Coverage for Dynamic Sensor Networks</b> <i>Simone Gabriele and Paolo Di Giamberardino</i> .....	35
<b>An Investigation into Clustering Routing Protocols for Wireless Sensor Networks</b> <i>Abdulazeez F. Salami, Farhat Anwar and Akhmad Unggul Priantoro</i> .....	48
<b>Data Fusion Functions: Applications to Sensor Networks</b> <i>Vinay Kumar Deekonda, Sankara Sastry Korada and Ramamurthy Garimella</i> .....	62
<b>High Fidelity Simulation of Network Nodes with RF-Ranging Capabilities</b> <i>Hamed Bastani and Andreas Birk</i> .....	73
<b>RFID for Location Proposes Based on the Intermodulation Distortion</b> <i>Hugo Gomes, Nuno Borges Carvalho</i> .....	85
<b>Design and Manufacturing Precise Wireless Car Engine's Speed Sensor</b> <i>Amir Mahyar Khoraani, Mir Saeed Safizadeh</i> .....	97
<b>Channel Estimation of WCDMA with OFDM Signal</b> <i>N. R. Raajan, Y. Venkataramani, T. R. Sivaramakrishnan</i> .....	107
<b>Rearranging Structure for WCDMA over GSM</b> <i>N. R. Raajan, Y. Venkataramani, T. R. Sivaramakrishnan</i> .....	114
<b>Simulation Study of OFDM, COFDM and MIMO-OFDM System</b> <i>Mrutyunjaya Panda and Dr. Sarat Ku. Patra</i> .....	123
<b>An Efficient Method for Extraction of Transfer Function of H-Tree Clock Distribution Networks</b> <i>Fahimeh Alsadat Hosseini and Nasser Masoumi</i> .....	134
<b>Three-dimensional Quantitative Visualization from a Single Image</b> <i>Yuichiro Oya, Kikuhito Kawasue</i> .....	142
<b>Modeling and Analysis of Micro Fluidic Channels</b> <i>M. Shanmugavalli, M. Umamathy, G. Uma</i> .....	155

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

## Data Fusion Functions: Applications to Sensor Networks

Vinay Kumar DEEKONDA, Sankara Sastry KORADA  
and \*Ramamurthy GARIMELLA

Department of Electronics and Communication Engineering

Indian Institute of Technology Guwahati, Guwahati- 781039, India

\* International Institute of Information Technology, Gachibowli, Hyderabad, India – 500032

Tel.: 91-40-6653 1000, fax: 91-40-6653 1413

E-mail: d.vinay@iitg.ernet.in, k.sastry@iitg.ernet.in, rammurthy@iiit.ac.in

*Received: 14 May 2009 /Accepted: 15 July 2009 /Published: 20 July 2009*

---

**Abstract:** A median-based sensor fusion function has been proposed which satisfies local Lipschitz condition and is fault tolerant in presence of outliers. Some of the existing fusion functions have also been merged to produce a hybrid fusion function which satisfies local Lipschitz condition and retains the better properties of each component function. Equivalence has been established between two existing fusion functions under certain conditions. *Copyright © 2009 IFSA.*

**Keywords:** Fault tolerance, Sensor fusion, Hybrid fusion functions

---

### 1. Introduction

Wireless Sensor Networks have established their utility in a very large number of civil and military applications. The main advantage of this technology is the increasing availability of cheaper sensor nodes with higher data processing capabilities and better scalability with perhaps tens of thousands of sensor nodes deployed in some custom applications. Wireless communication has enabled huge number of sensors to stay connected. This has also opened up a new domain for data integration techniques to hierarchically pass useful information from cluster nodes to localized sink nodes and finally to a central information processing station. We refer to this data integration as sensor fusion.

Fault-tolerant sensor fusion is a necessity where some of the nodes in a sensor network may turn faulty due to battery exhaustion or physical wear and tear. This requires robust transmission of sensor data to higher levels in the sensor network hierarchy. The sensor estimates may be crisp valued or interval

valued (due to their tolerance limits). As a result, the fused estimate may be crisp or interval valued. There are several approaches to sensor fusion. Using Fusion functions is one of the several approaches. In this paper, we consider the case where the sensor output is interval valued and is a bounded and connected subset of real line  $\mathbb{R}$ . The fused output from a fusion function is also interval.

Given below are definitions for some of the terms used in this paper:

*Abstract sensor*: It is a sensor that reads a physical parameter and gives out an abstract interval estimate  $I_s$  which is bounded and connected subset of real line  $\mathbb{R}$ .

*Correct Sensor*: It is an abstract sensor where the interval estimate contains the true value of the measured parameter.

*Faulty sensor*: It is an abstract sensor where the interval estimate does not contain the true value of the measured parameter.

Let  $I_1, I_2, I_3, \dots, I_n$  be the interval estimates from  $n$  abstract sensors and let there be  $f$  faulty sensor among them.

We summarize the some of the known fusion functions below [1]:

**M** function of Marzullo [2] :  $M([I_1, I_2, I_3, \dots, I_n])$  is defined to be the smallest interval that contains the intersections of  $n-f$  intervals. It is guaranteed to contain the true value provided the number of faulty sensors is at most  $f$ .

**F** function of Schmid and Schossmailer[3] :  $F([I_1, I_2, I_3, \dots, I_n])$  returns a closed interval  $[a, b]$  where  $a$  is the  $(f+1)^{th}$  maximum left end point and  $b$  is the  $(f+1)^{th}$  minimum right end point of the intervals *i.e.* there are exactly  $f$  left end points to the right of  $a$  when the left end points are sorted in non decreasing order and similarly there are  $f$  right end points to the left of  $b$  when right end points are sorted in non decreasing order.

**Q** function of Prasad et al.[4] : The  $\Omega(x)$  function, also called the overlap function, gives the number of intervals overlapping at  $x$ . Multi Resolution Analysis(MRA) performed on the  $\Omega$  function results in an integration interval with the highest peak and widest spread at a certain resolution.

**N** function: **N** function improves over the  $\Omega$  function to only generate the interval with the overlap function having the range  $[n-f, n]$ .

Conventional fault models consider correct and faulty sensors and their corresponding interval estimates. Further, tamely faulty and wildly faulty sensors are so defined based on whether or not their interval estimates overlap that of correct sensors, respectively. With this fault model, it is realized that the fused estimate provided by the **F** function is optimal.

The fault model considered for the median-based fusion function **G** proposed in this paper is such that the sensor measurements contain the sensed value corrupted by impulsive noise. With this fault model, median is a better fault tolerant estimate than the mean.

In this paper, we also propose a Hybrid fusion function which integrates the existing fusion functions to provide a single fused interval having the desirable properties of component fusion functions.

## 2. Median-based Fusion Function

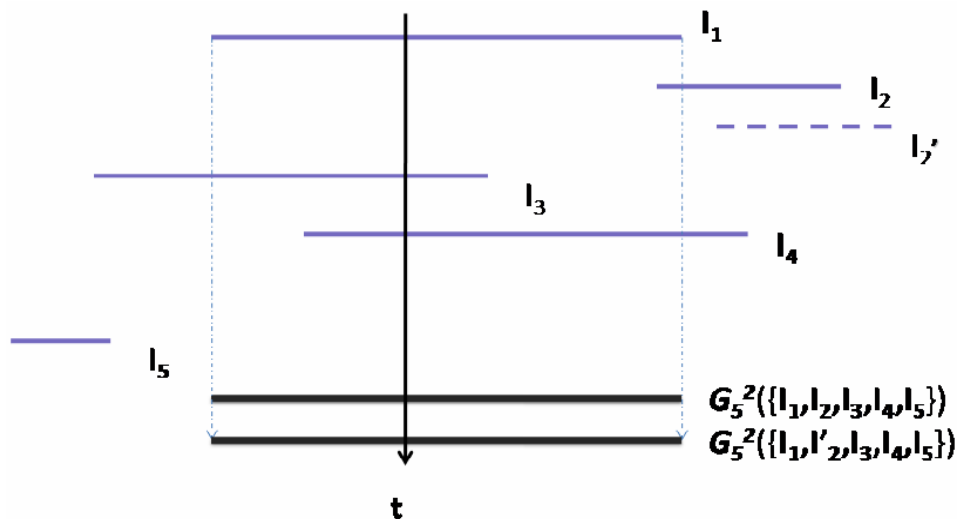
Median filtering approach provides a robust, fault tolerant estimate in signal processing.

Here we provide an example to compare median and mean of a set of values.

Let the crisp values be {10, 9, 11, 12, 10, 8, 24, 26, 30}. The last three values are outliers (extreme values) and are given out by faulty sensors. The mean gives the estimate as 15.55 while the median gives the estimate as 11. Here we observe that the mean gives a poor estimate than the median.

We will study the median based fusion function along with proof of its Lipschitz criterion.

**Median-based Fusion Function G:** **G** function returns the fused estimate as being the output interval whose left bound is the median of all left end points and whose right bound is the median of all the right end points, i.e., the interval is [*Median of n left end points, Median of n right end points*] where *n* is the number of sensor nodes in the cluster. Here the number of faulty sensors *f* must satisfy  $f < \lceil n/2 \rceil$ . **G** function also satisfies local Lipschitz condition with respect to uniform metric as in [6]. This means that for small changes in input intervals, the change in output interval is also very small, if any. This is illustrated in Fig 1.



**Fig. 1.** Example of Median based fusion function **G** with  $n=5$  and  $f=2$ . There is no impact of change in  $I_2$  to  $I_2'$ . Note that *t* represents the true value of the measured parameter.

The principle behind the median based fusion function can be extended to create a family of related rank order statistic based fusion functions. In general, we can take the *i*<sup>th</sup> largest value of all left end points as the left bound and the *i*<sup>th</sup> largest value of all right end points as the right bound.

For example, in case of forest fires, we need to have the information about the highest temperature in an area to generate an alarm, in which case the *n*<sup>th</sup> largest left and right end points are taken. Similarly, in polar/cold regions, minimum temperature must be emphasized.

The following Lemma gives the Lipschitz condition criterion for the median based fusion function.

**Lemma 1:** The median based fusion function ‘**G**’ satisfies Lipschitz condition for the uniform metric  $\mu$  which means that for any  $\delta > 0$  and any two sets of interval readings  $I = \{ I_1, I_2, I_3, \dots, I_n \}$  and  $I' = \{ I_1', I_2', I_3', \dots, I_n' \}$  with at most  $f < \lceil n/2 \rceil$  of those being faulty,

$$\mu(G_n^f(I), G_n^f(I')) < \delta, \text{ provided that } \mu(I_i, I_i') < \delta \text{ for } 1 \leq i \leq n.$$

**Proof:** Let  $\mathbf{G} = G_n^f(I)$  and  $\mathbf{G}' = G_n^f(I')$ .

Let  $I_i = [x_i, y_i], x_i < y_i$ .

$I'_i = [x'_i, y'_i], x'_i < y'_i$ .

Note that  $x'_i = x_i + l_i, y'_i = y_i + r_i$ , where  $-\delta < l_i, r_i < \delta, 1 \leq i \leq n$ .

We consider two cases:  $n$  is even and  $n$  is odd.

**Case (I):**  $n$  is odd.

$$\text{left}(\mathbf{G}) = x_j = \left[\frac{n+1}{2}\right]^{\text{th}} \text{max. of } \{x_1, x_2, x_3, \dots, x_n\}.$$

$$\text{right}(\mathbf{G}) = y_j = \left[\frac{n+1}{2}\right]^{\text{th}} \text{max. of } \{y_1, y_2, y_3, \dots, y_n\}.$$

$$\text{left}(\mathbf{G}') = x'_{j'} = \left[\frac{n+1}{2}\right]^{\text{th}} \text{max. of } \{x'_1, x'_2, x'_3, \dots, x'_n\}.$$

$$\text{right}(\mathbf{G}') = y'_{j'} = \left[\frac{n+1}{2}\right]^{\text{th}} \text{max. of } \{y'_1, y'_2, y'_3, \dots, y'_n\}$$

Here  $\mu((x_j, y_j), (x'_{j'}, y'_{j'})) = \max\{|x_j - x'_{j'}|, |y_j - y'_{j'}|\}$ .

To prove  $\mu((x_j, y_j), (x'_{j'}, y'_{j'})) < \delta$ , it is enough if we prove  $|x_j - x'_{j'}| < \delta, |y_j - y'_{j'}| < \delta$ .

Thus we deal with  $\text{left}(\mathbf{G})$  and  $\text{right}(\mathbf{G})$  separately and the proof is similar for both.

We need to prove that  $|x_j - x'_{j'}| < \delta$  if  $\mu(I_i, I'_i) < \delta$  for  $1 \leq i \leq n$ .

Consider  $x'_j = x_j + l_j$ .

**Case (1a):**

$$\begin{aligned} x'_j &\leq x'_{j'} \\ x'_j &= x_j + l_j, |l_j| < \delta \\ \Rightarrow x_j - \delta &\leq x'_j < x'_{j'} \end{aligned}$$

$$\Rightarrow x_j - \delta < x'_{j'} \tag{1a}$$

**Case (1b):**

$$x'_j > x'_{j'}$$

Suppose  $\exists$  an  $x_k \ni x_k \geq x_j$  and  $x'_k \leq x'_{j'}$ .

We have  $x_j \leq x_k \Rightarrow x_j - \delta \leq x_k - \delta < x_k + l_k \leq x'_k$

$$\Rightarrow x_j - \delta < x'_{j'} \quad (1b)$$

Therefore from (1a) and (1b) we get

$$x_j - \delta < x'_{j'} \quad (1)$$

We need to prove the existence of such an  $x_k$ . We adopt the method 'Proof by contradiction'.

Assume no such  $x_k$  exists i.e.  $\forall x_k, x_k \geq x_j \Rightarrow x'_k > x'_{j'}$ .

$x_k > x_j \Rightarrow k$  can take almost  $\frac{n-1}{2}$  values.

We arrive at a contradiction.

Therefore  $\exists$  an  $x_k$  such that  $x_k \geq x_j$  and  $x'_k \leq x'_{j'}$

Consider  $x'_{j'}$

**Case (2a):**

$$\begin{aligned} x_{j'} &= x'_{j'} - l_{j'} \leq x_j \\ \Rightarrow x'_{j'} &\leq x_j + l_{j'} < x_j + \delta \\ \Rightarrow x'_{j'} &< x_j + \delta \end{aligned} \quad (2a)$$

**Case(2b):**

$$x_{j'} > x_j$$

Suppose  $\exists$  an  $x_k \ni x_k \leq x_j$  and  $x'_k \geq x'_{j'}$ .

We have  $x_k \leq x_j \Rightarrow x'_k \leq x_k + l_k < x_k + \delta \leq x_j + \delta$

$$\Rightarrow x'_{j'} < x_j + \delta \quad (2b)$$

Therefore from case (2a) and case (2b), we get

$$x'_{j'} < x_j + \delta \quad (2)$$

We need to prove the existence of such an  $x_k$ .

Assume no such  $x_k$  exists i.e.  $\forall x_k, x_k \leq x_j \Rightarrow x'_k < x'_{j'}$ .

$x_k \leq x_j \Rightarrow k$  can take almost  $\frac{n+1}{2}$  values.

But  $x'_k \leq x'_{j'} \Rightarrow k$  can take almost  $\frac{n-1}{2}$  values.

We arrive at a contradiction which implies that such an  $x_k$  exists.

Therefore  $\exists$  an  $x_k$  such that  $x_k \leq x_j$  and  $x'_k \geq x'_{j'}$ .

From (1) and (2), we have

$$x_j - \delta \leq x'_{j'} \leq x_j + \delta \text{ or } |x_j - x'_{j'}| < \delta$$

**Case (II):**  $n$  is even

The proof is similar for even number of sensors except that we need to prove for  $x_{j_1}$  and  $x_{j_2}$  separately where  $x_j = \frac{(x_{j_1} + x_{j_2})}{2}$  and  $x'_{j'} = \frac{(x'_{j_1'} + x'_{j_2'})}{2}$

$$x_{j_1} \text{ and } x_{j_2} \text{ are } \left[\frac{n}{2}\right]^{th} \text{ and } \left[\frac{n+1}{2}\right]^{th} \text{ max. of } \{x_1, x_2, x_3, \dots, x_n\}.$$

$$x'_{j_1'} \text{ and } x'_{j_2'} \text{ are } \left[\frac{n}{2}\right]^{th} \text{ and } \left[\frac{n+1}{2}\right]^{th} \text{ max. of } \{x'_1, x'_2, x'_3, \dots, x'_n\}.$$

Also we know that if  $|x_{j_1} - x'_{j_1'}| < \delta$  and  $|x_{j_2} - x'_{j_2'}| < \delta$ , then

$$\begin{aligned} \left| \frac{(x_{j_1} + x_{j_2})}{2} - \frac{(x'_{j_1'} + x'_{j_2'})}{2} \right| &< \left| \frac{x_{j_1} - x'_{j_1'}}{2} \right| + \left| \frac{x_{j_2} - x'_{j_2'}}{2} \right| < \frac{\delta}{2} + \frac{\delta}{2} \\ &\Rightarrow |x_j - x'_{j'}| < \delta. \end{aligned}$$

Similarly, we can prove that  $|y_j - y'_{j'}| < \delta$  Q.E.D

**Corollary:** Similar argument can be applied to prove the local Lipschitz condition for the uniform metric for a function that selects the minimum/maximum of the left and right end points. This is useful where we are concerned only with the minimum or maximum of all the readings, for example, in case of monitoring forest fires or monitoring temperature in polar/cold regions.

### 3. Hybrid Fusion Functions

In this section we present a method to integrate the existing fusion functions to provide a single output interval. This can be extended to any number of component fusion functions. Moreover, if each of the fusion functions satisfies Lipschitz condition, the hybrid fusion function also satisfies Lipschitz condition. We define the fusion function  $H$  as

$$H\{I_1, I_2, I_3, \dots, I_n\} = A \cap B \cap C,$$

where

$$\begin{aligned} A &= M \{I_1, I_2, I_3, \dots, I_n\} \\ B &= F \{I_1, I_2, I_3, \dots, I_n\} \\ C &= N \{I_1, I_2, I_3, \dots, I_n\} \end{aligned}$$

We now prove the Lipschitz condition for the intersection of two fusions functions each satisfying Lipschitz condition independently for a certain metric and extend our result, by induction to the Hybrid fusion function,  $H$ , as defined above.

**Lemma 2:** If  $f$  and  $g$  are two functions satisfying Local Lipschitz condition for the uniform metric  $\mu$  over two sets of intervals  $I, I'$ , then their intersection  $f \cap g$  satisfies the local Lipschitz condition.

**Proof:** Let the vectors  $I, I'$  be sensor readings, i.e.,

$$I = \{[x_1, y_1], [x_2, y_2], \dots, [x_n, y_n]\},$$

$$I' = \{[x_1, y_1], [x_2, y_2], \dots, [x_n, y_n]\}.$$

We have  $\mu(f(I), f(I')) < \delta$  and  $\mu(g(I), g(I')) < \delta$  if  $\mu((x_i, y_i), (x'_i, y'_i)) < \delta \forall i \in \{1, 2, \dots, n\}$ .

Here  $\mu((x, y), (v, w)) = \max\{|v - x|, |w - y|\}$ .

To prove  $\mu((x_i, y_i), (x'_i, y'_i)) < \delta$ , it is enough if we prove  $|x_i - x'_i| < \delta$  and  $|y_i - y'_i| < \delta$ .

Let  $f(I), f(I')$  be  $[x_f, y_f]$  and  $[x'_f, y'_f]$  respectively.

Let  $g(I), g(I')$  be  $[x_g, y_g]$  and  $[x'_g, y'_g]$  respectively.

Since  $f$  and  $g$  satisfy Lipschitz condition,

$$|x_f - x'_f| < \delta \text{ and } |y_f - y'_f| < \delta$$

$$|x_g - x'_g| < \delta \text{ and } |y_g - y'_g| < \delta$$

In order to prove that  $f \cap g$  satisfies Lipschitz condition, we need to prove that

$$\min(y_f, y_g) - \min(y'_f, y'_g) < \lambda_2 \delta,$$

where  $\lambda_1, \lambda_2$  are some positive constants.

Consider (3)

$$\max(x_f, x_g) = \frac{1}{2} [x_f + x_g + |x_f - x_g|]$$

Similarly,

$$\max(x'_f, x'_g) = \frac{1}{2} [x'_f + x'_g + |x'_f - x'_g|]$$

Equation (3) implies

$$\frac{1}{2} |x_f - x'_f + x_g - x'_g + |x_f - x_g| - |x'_f - x'_g|| < \frac{1}{2} (\delta + \delta + |x_f - x'_f + x_g - x'_g|) < \frac{1}{2} (4\delta) = 2\delta$$

Note: Here we have used the ordering property that  $|a| - |b| < |a - b|$

Similarly we can prove (4) using

$$\min(a, b) = \frac{a + b - |a - b|}{2}$$

Therefore  $f \cap g$  satisfies Lipschitz condition if  $f$  and  $g$  satisfy Lipschitz condition individually for the uniform metric.

**Corollary:** By induction, it can be inferred that if  $f_1, f_2, \dots, f_M$  are fusion functions each satisfying Lipschitz condition, then  $f_1 \cap f_2 \cap f_3 \cap \dots \cap f_M$  also satisfies Lipschitz condition for any finite  $M$ .

#### 4. M function and F function: Condition for Equivalence

In this section, we compare M function and F function and establish an equivalence relation between the two, subject to certain conditions. It is established that M function does not satisfy Lipschitz condition but F function does. The following lemma provides the condition under which M function satisfies Lipschitz condition.

**Lemma 3:** M function is equivalent to F function provided

$$\{\text{maximum of all left end points}\} \leq \{\text{minimum of all right end points}\}.$$

In other words, each intersection of any  $n - f$  intervals is non-empty.

**Proof:** Let  $\{x_1, x_2, x_3, \dots, x_n\}$  represent the set containing all left end points sorted in non-decreasing order and  $\{y_1, y_2, y_3, \dots, y_n\}$  represent the set containing all the right end points sorted in non decreasing order.

Total number of intersections of  $n-f$  intervals chosen from  $n$  intervals is given by  $C_{n-f}^n$ . Alternatively, by looking at the left end points, we can classify these total numbers of intersections into

Number of intersections having  $x_n$  as left bound =  $C_{n-f-1}^{n-1}$ .

Number of intersections having  $x_{n-1}$  as left bound =  $C_{n-f-1}^{n-2}$  and so on.

Therefore we have number of intersections having  $x_{n-k+1}$  as left bound =  $C_{n-f-1}^{n-k}$ .

If  $x_{n-k+1}$  turn out to be the minimum among left bounds of all  $C_{n-f}^n$  intersections, then we have

Solving for  $k$ , we get  $k = f + 1$ .

i.e. union of all  $C_{n-f}^n$  intersections has its left bound as  $(f+1)^{\text{th}}$  maximum left bound(i.e.  $x_{n-f}$ ) which is same as that of left bound of F function.

Similar argument can be applied to show that the right bound of the union of all intersections of  $n-f$  intervals is the  $(f + 1)^{\text{th}}$  right bound (i.e.,  $y_{f+1}$ ) when sorted in non decreasing order. Therefore M



## 5. Uncertain Number of Faulty Sensors: Sensor Fusion

In this section we propose an algorithm for sensor fusion where the number of faulty sensors,  $f$  has a discrete probability distribution. The proposed algorithm is as follows:

Given: The abstract readings are  $\{I_1, I_2, I_3, \dots, I_n\}$  where the minimum and maximum possible values for the number of faulty sensors are  $f_{\min}$  and  $f_{\max}$  respectively. Thus the discrete probability distribution of  $f$  has the support  $\{f_{\min}, f_{\min} + 1, f_{\min} + 2, \dots, f_{\max} - 1, f_{\max}\}$ .

The probability mass function is given by

$p_i$  = probability that the number of faulty sensors is  $i$ ,

$$i = f_{\min}, f_{\min} + 1, f_{\min} + 2, \dots, f_{\max} - 1, f_{\max}.$$

### Algorithm:

1) Consider the fusion function  $F$ .

**Calculate** the fused interval estimates corresponding to each

$$i, i = f_{\min}, f_{\min} + 1, f_{\min} + 2, \dots, f_{\max} - 1, f_{\max}.$$

2) **Let** the set of fused interval estimates be  $J_i, i = f_{\min}, f_{\min} + 1, f_{\min} + 2, \dots, f_{\max} - 1, f_{\max}$ .

3) **Take** the midpoint of each fused interval estimate,

$$J_i^{(mid)}, i = f_{\min}, f_{\min} + 1, f_{\min} + 2, \dots, f_{\max} - 1, f_{\max}.$$

4) **Calculate** the first moment  $\mu$  of the distribution of the midpoints.

$$\mu = \sum_{i=f_{\min}}^{f_{\max}} p_i J_i^{(mid)}$$

5) **Calculate** the second moment and then variance,  $\sigma^2$  of the fused estimates.

$$\sigma^2 = \sum_{i=f_{\min}}^{f_{\max}} p_i (J_i^{mid})^2 - \mu^2$$

6) **Calculate** the standard deviation  $\sigma$ .

7) **Declare** the estimate as  $[\mu - \sigma, \mu + \sigma]$  or  $[\mu - 2\sigma, \mu + 2\sigma]$ , etc depending upon the required fidelity.

## 6. Conclusions

In this paper we proposed a novel median based sensor fusion function,  $F$  and hybrid fusion function  $H$ , for fault tolerant sensor fusion and proved their Lipschitz continuity. This function considers the impulsive noise model different from the  $F$  function. We have also established the equivalence relation

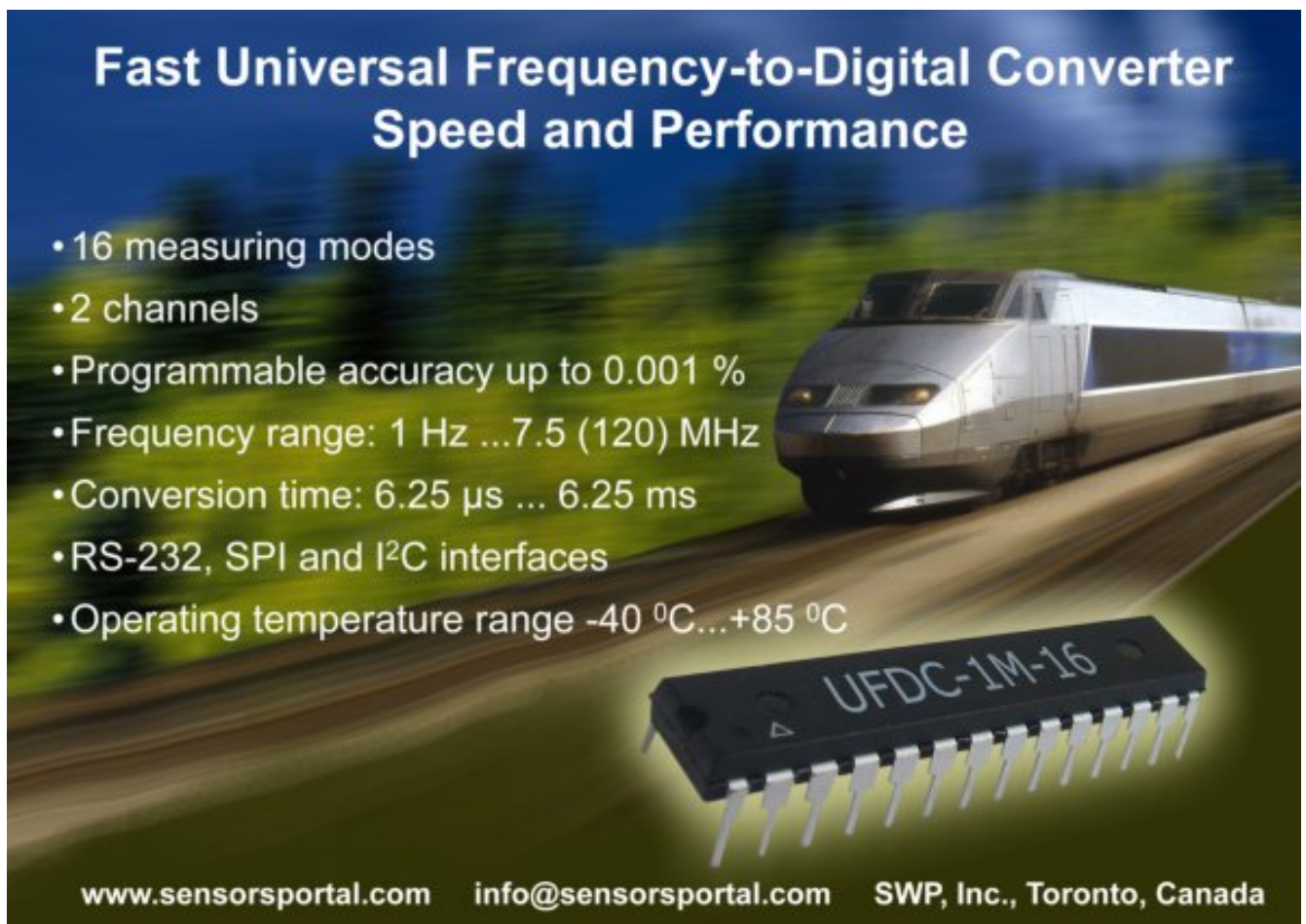
between **M** function and **F** function under certain conditions. In situations where these conditions are satisfied, **M** function can be replaced with **F** function to obtain the same performance with lesser computational overhead. Probability distribution for the number of faulty sensors has also been explored and an algorithm for sensor fusion has also been proposed. Future work would be on applying these fusion functions to real world applications.

## References

- [1]. Distributed Sensor Networks - A review of recent research, *Journal of Franklin Institute*, JFI 338, 2001, pp. 655-668.
- [2]. K. Marzullo, Tolerating failures of continuous values sensors, *ACM Trans Comput. Systems*, 8, 4, 1990, pp. 284-304.
- [3]. U. Schmid, K. Schossmaier, *How to reconcile fault-tolerant interval intersection with the Lipschitz condition?* *Distributed Computing*, Vol. 14, Issue 2, 2001, pp 101-111.
- [4]. L. Prasad, S. S. Iyengar, R. L. Rao, Fault-tolerant sensor integration using multi-resolution decomposition, *Phys. Rev.*, E 49, 4, 1994, pp. 3452-3461.
- [5]. E. Cho, S. S. Iyengar, K. Chakrabarty, H. Qi, A new fault tolerant sensor integration function satisfying local Lipschitz condition, 2000, submitted for publication.
- [6]. L. Lamport, Synchronizing time servers, Technical Report, 18, *Digital System Research Center*, 1987.

---

2009 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.  
(<http://www.sensorsportal.com>)



## Fast Universal Frequency-to-Digital Converter Speed and Performance

- 16 measuring modes
- 2 channels
- Programmable accuracy up to 0.001 %
- Frequency range: 1 Hz ...7.5 (120) MHz
- Conversion time: 6.25  $\mu$ s ... 6.25 ms
- RS-232, SPI and I<sup>2</sup>C interfaces
- Operating temperature range -40 °C...+85 °C

**UFDC-1M-16**

[www.sensorsportal.com](http://www.sensorsportal.com)    [info@sensorsportal.com](mailto:info@sensorsportal.com)    SWP, Inc., Toronto, Canada

## 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

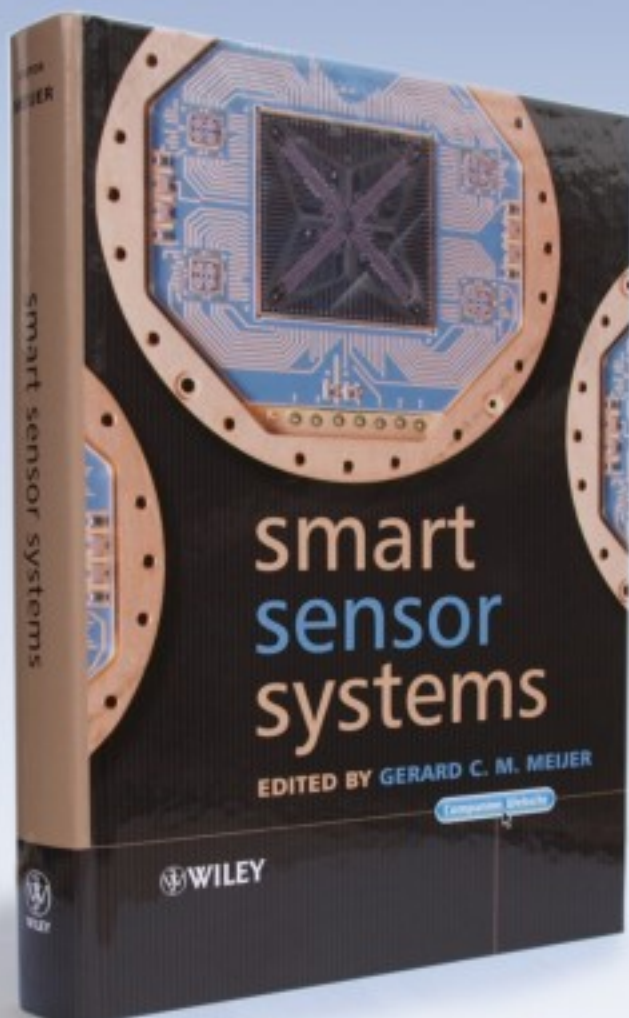
Articles should be written in English. Authors are invited to submit by e-mail [editor@sensorsportal.com](mailto:editor@sensorsportal.com) 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation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

### Advertising Information

Advertising orders and enquires may be sent to [sales@sensorsportal.com](mailto:sales@sensorsportal.com) Please download also our media kit: [http://www.sensorsportal.com/DOWNLOADS/Media\\_Kit\\_2009.pdf](http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.pdf)

 **WILEY**  
1807-2007

KNOWLEDGE FOR GENERATIONS



**'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](http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm)

**[www.sensorsportal.com](http://www.sensorsportal.com)**