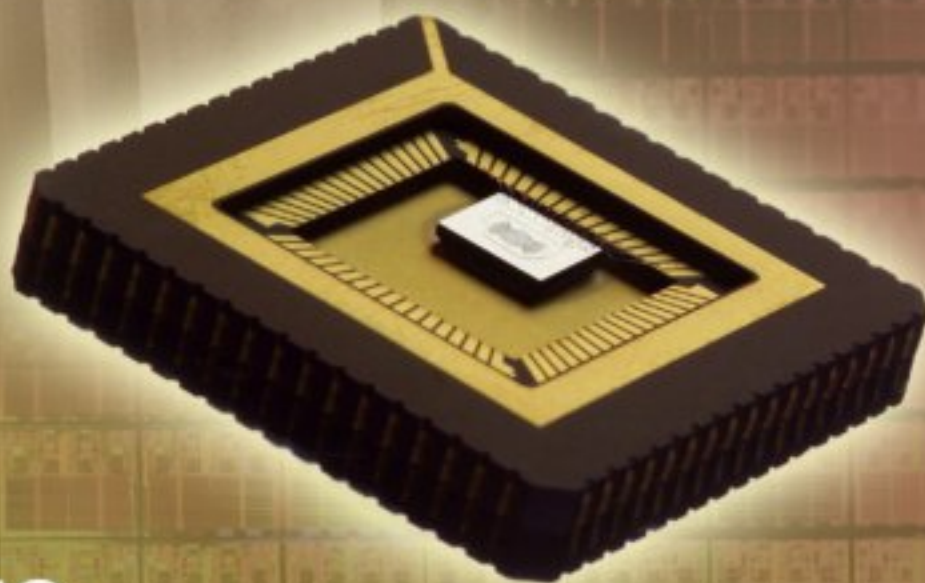


ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 127
4 / 11



MEMS and Modern Technologies

International Frequency Sensor Association Publishing





Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, fax: +34 93 401 1989, 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, Karthikeyan, 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
Ayesha, Aladdin, De Montfort University, UK
Azamimi, Azian binti Abdullah, Universiti Malaysia Perlis, Malaysia
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Monitors 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
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, 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
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, 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
Homontcovschi, 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
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kockar, Hakan, Balikesir University, Turkey
Kong, Ing, RMIT University, Australia

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
Li, Yuefa, Wayne State University, USA
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
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
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 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
Rastogi Shiva, K., University of Idaho, USA
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 Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica 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
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Shah, Kriyang, La Trobe University, Australia
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
Yufera 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 127
Issue 4
April 2011

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Going Fabless with MEMS <i>Bhaskar Choubey</i>	1
Micromachined Polycrystalline Si Thermopiles in a T-shirt <i>Vladimir Leonov, Yvonne van Andel, Ziyang Wang, Ruud J. M. Vullers and Chris Van Hoof</i>	15
Virtual Fabrication of Silicon Nitride Based Multifunctional MEMS Pressure Sensor <i>Mahesh Kumar Patankar</i>	27
General Development of a New Hall Effect Sensor <i>Vlassis N. Petoussis, Panos D. Dimitropoulos, George Stamoulis</i>	36
Inspection of Pipe Inner Surface using Advanced Pipe Crawler Robot with PVDF Sensor based Rotating Probe <i>Vimal Agarwal, Harutoshi Ogai, Kentarou Nishijima and Bishakh Bhattacharya</i>	45
Ultrasonic System Approach to Obstacle Detection and Edge Detection <i>Yin Thu Win, Hla Thar Htun, Nitin Afzulpurkar, Chumnarn Punyasai</i>	56
Monitoring of Various Glucose Concentrations Based on Optical Spectroscopic Reflectometry <i>Hariyadi Soetedjo</i>	69
Studies of Gas Sensing Performance of Barium Zirconate (BaZrO₃) <i>R. M. Chaudhari, V. B. Gaikwad, P. D. Hire, R. L. Patil, S. D. Shinde, N. U. Patil, G. H. Jain.</i>	76
Modeling and System-level Simulation of Force-balance MEMS Comb Accelerometers <i>Hao Chen, Limei Xu</i>	88
Design and Fabrication of a Lab-on-a-chip for Point-of-care Diagnostics <i>Anne Balck, Monika Michalzik, Laila Al-Halabi, Stefan Dübel, and Stephanus Büttgenbach</i>	102

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>

Call for Books Proposals

Sensors, MEMS, Measuring instrumentation, etc.

International Frequency Sensor Association Publishing



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.

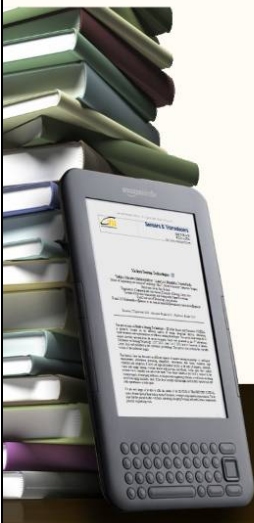
IFSA recognizes the value to our customers of timely information, so we produce your book quickly: 2 months publishing schedule compared with other publishers' 5-18-month schedule.

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.

Mobile Advertising Solutions for Sensor Industry: How to reach 80,000+ addressable mobile audiences?

An industry first Smartphone mobile advertising solution for sensors manufacturers and distributors



50% OFF
for limited time interval



Create your account today and use a **discount coupon code ls10001** to start advertising your sensors now:

https://www.lesensor.com/sensor/Profiles/CreateNewAccount.aspx?sensor_portal=ls10001



Inspection of Pipe Inner Surface using Advanced Pipe Crawler Robot with PVDF Sensor based Rotating Probe

¹Vimal AGARWAL, ²HARUTOSHI Ogai, ²KENTAROU Nishijima
and ³Bishakh BHATTACHARYA

¹ System Engineer, Infosys Technologies Limited, Bangalore, India

Tel.: +91-9620770832

²Department of Mechanical Engineering, Indian Institute of Technology Kanpur, India-208016

Tel.: +91-0512-2597824

³ Graduate school of Information, Production and Systems, Waseda University,
2-7 Hibikino, Wakamatsu-Ku, Kitakyushu-shi, Fukuoka, Japan

Tel.: +81-93-692-5147

E-mail: vimal_agarwal01@infosys.com, ogai@waseda.jp, kentaronishijima@fuji.waseda.jp,
bishakh@iitk.ac.in

Received: 18 March 2011 /Accepted: 22 April 2011 /Published: 30 April 2011

Abstract: Due to corrosive environment, pipes used for transportation of water and gas at the plants often get damaged. Defects caused by corrosion and cracking may cause serious accidents like leakage, fire and blasts. It also reduces the life of the transportation system substantially. In order to inspect such defects, a Polyvinylidene Fluoride (PVDF) based cantilever smart probe is developed to scan the surface quality of the pipes. The smart probe, during rotation, touches the inner surface of the pipe and experience a broad-band excitation in the absence of surface features. On the other hand, whenever the probe comes across any surface projection, there is a change in vibration pattern of the probe, which causes a high voltage peak/pulse. Such peaks/pulses could give useful information about the location and nature of a defect. Experiments are carried out on different patterns, sizes and shapes of surface projections artificially constructed inside the pipe. The sensor system has reliably predicted the presence and distribution of projections in every case. It is envisaged that the new sensing system could be used effectively for pipe health monitoring. *Copyright © 2011 IFSA.*

Keywords: Pipeline inspection robot, Smart sensors, PVDF, Structural health monitoring, Wireless signal transmission.

1. Introduction

Very often, it is necessary to monitor the surface roughness of the pipes which transport water and gas for cracks, obstructive growths as well as shape deformation on a regular basis to forestall any accident. In cylindrical pipes, traditionally, the surface integrity is checked either manually or by using laser probes [1]. While the manual inspection relies heavily on human skill, the laser sensing system is quite expensive. Hence, it is convenient and economic to have a setup that can move inside the pipe and make such inspection automatically by using a rotating probe. Crawler robots are being developed for pipe –health monitoring, but most of them rely on wired signal transmission which causes problems with the movement of the robot inside the pipe. Dongmei Wu *et al.* [2] have proposed an inspection robot using a wireless radio communication system useful for long complex pipes. The communication properties of radio signals inside pipes of diameter 30 cm and length 10 cm was measured using such device.(see Fig. 1-a).

A wireless radio signal from the steel pipe inlet was emitted and it was measured in the steel pipe outlet as shown in Fig. 1. The Radio signal at different antenna positions was measured. The transmission loss from transmitting antenna input to the corresponding receiving antenna output was 14 ± 6 dB in 2.4 GHz band. Typical output corresponding to different band and position of antenna are shown in Fig. 1-b.

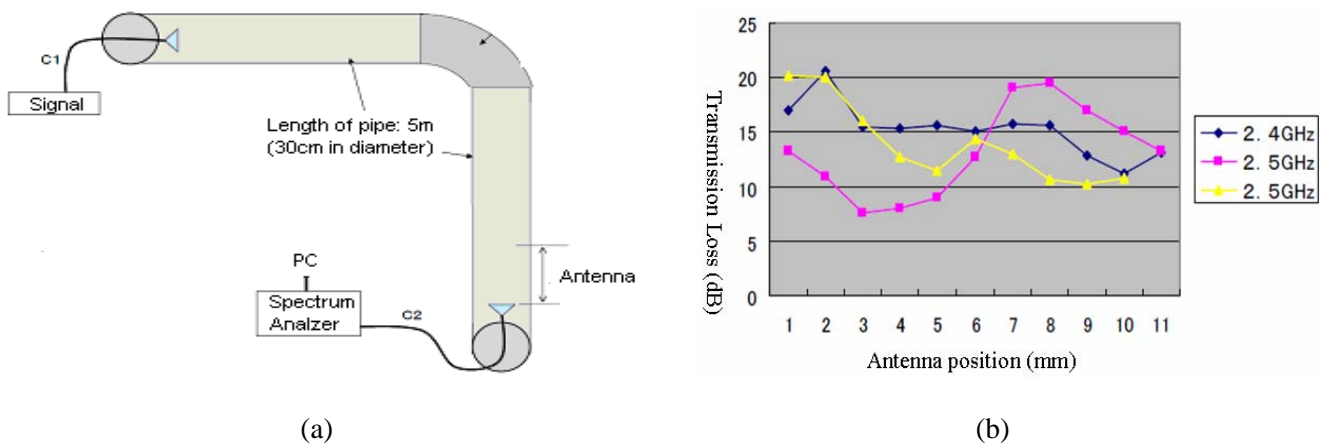


Fig. 1. (a) Transmission test in steel pipe; (b) Measurement result in steel pipe.

The experiments have proved that signals could be transmitted well in steel pipes within 100 m. The objective of this paper is to establish the usability of a new PVDF based cantilever smart probe as a sensor to sense finite sized discontinuities over a surface using the above mentioned inspection robot [2]. This is done by conducting a series of experiments by testing the beam against surfaces with known projections and studying whether any meaningful results are obtained. The probes are made up of spring steel and used in cantilever mode. A PVDF patch is bonded to the cantilever for sensing vibration of the cantilever. The rotating probe is attached with the robot and rotated by a motor as shown in Fig. 4. Whenever the system touches the defected area, the PVDF film could detect the presence of defect due to the change in dynamic strain. This strain change of the PVDF film can be measured as voltage change. Thus, the feature of the defect can be predicted by observing the voltage peak/pulse.

2. Previous Work

The idea of using cantilever beam for surface roughness measurement is already in use in atomic force microscopes, at a very high precision level. In these systems, deflection is measured by the reflection of a laser ray off the beam, falling on a photodiode. Beaulieu *et al.* [3] have analyzed such laser beam deflection based systems used with cantilever probes. It is apparent and is also suggested by them that in addition to the point at which the laser beam hits the cantilever, the slope also has to be taken into consideration to determine the position where the ray gets reflected to. The slope of the cantilever varies with position and as deflection changes, the point of reflection shift. However, with proper choice of different parameters, it is possible to obtain a near linear relationship between Photo Sensitive Diode signal and the actual deflection of the cantilever. Work has been done in determining the sensitivity of a cantilever depending upon its length, stiffness of the contact surface and the shape of the cantilever [4]. Stiffness of the contact surface plays an important role in determining the sensitivity of the beam with respect to its shape. Two shapes of the beam were considered straight (uniform) and “V” shaped. However, it was observed that for stiff materials, response of both the shapes tends to converge. The beam deflection considered is quasi static in nature.

It is frequently observed that when a string/beam is oscillating, the vibrating parts are seen blurred. This motion blur is highest near the antinodes and decreases as we approach the nodes. This phenomenon is studied analytically by Slangen *et al.* [5]. When coherent light falls on an optically rough surface, the grainy aspect detected is known as the speckle of the surface. The size of the speckle depends on the focal length and the aperture diameter of the optical system, Speckle interferometry is used to detect and measure such vibration mode shapes. Another technique of measuring deflection of cantilever using optical method is developed by Wong [6]. He has used a CCD camera instead of simple Photo sensitive strip. The lens of the camera is focused at a plane behind the reflecting surface and the change in intensity of the light reflected on the camera is recorded to measure surface roughness. Once the sensing is carried out, it is required to transfer the signals to the analyzer. Use of onboard data recorder like EPROM is used as one of the options [7]. After the completion of scanning, the chip is removed and the data can be retrieved using a decoder.

3. Properties and Function of PVDF

Shirinov *et al.* [8] report PVDF as low cost polymer pressure sensor. The output signal is of the order of few volts and the circuit required for signal detection is fairly simple. The measurement accuracy is usually limited by environmental conditions like temperature and humidity, as well as internal variations like pyroelectric effects and creep. Creep however can be taken care of by pre-stressing the composite in which the sensor is embedded. And if the environment is controlled, other variations can be neglected. PVDF thus forms a good pressure sensor. Piezo film sensors are usually supplied in the form of thin-film, typically ranging from 9 to 110 μm thicknesses. Due to the small cross-sectional area, a small load applied longitudinally along the plane of the film results in a very large axial stress in the film.

The electrical charge that is generated in the PVDF strip is proportional to the change in the mechanical stress [9]. If the sensor is bonded to the structure then the sensor output is proportional to changes in surface displacement. Hence this material can be used to detect variations in structural systems. Hua *et al.* [10] have discussed why PVDF film is better than other conventional health monitoring sensors like strain gauge, linear variable differential transducers (LVDT) and clip gauge from the point of view of external power supply.

The output response of the PVDF is proportional to the rate of change of the strain. The PVDF output voltage, $V_s(t)$ can be written as [11].

$$V_s(t) = G \frac{dQ(t)}{dt} = G \{K_s\}^T \{\dot{X}\} \quad (1)$$

where G is the constant gain of the charge amplifier. $\{K_s\}^T$ is the global coordinate system corresponding the spatial integration of a complex function over the surface of the PVDF film, $Q(t)$ is the charge accumulating in PVDF (which is a function of time) and $\{\dot{X}\}$ is the strain rate within the film.

The constitutive equation suggests the possibility of obtaining the measurement of the strain rate of the PVDF attached to the surface of the vibrating cantilever structure by simply measuring the voltage output of the PVDF film. The charge generated by PVDF is converted to voltage by a charge amplifier whose details are given in Section 5.

4. Details of Pipe Crawler Vehicle

A pipe crawler vehicle as shown in Fig. 2 is designed with the specifications provided in Table 1.

Table 1. Specifications of the Pipe Crawler vehicle.

Parameters	Values
Size	Length: 370 mm, Width: 180 mm, Height: 160
Working speed	13.7 m/min
Driveling mode	Double Motor
Electric Power	Rechargeable Batteries 7.2 V
Wireless Frequency	Apply to 2.4/5 GHz and Data Transmission

The vehicle is based on belt –driven translation mechanism. There are three basic elements in the vehicle .The front section carries the payload like camera, obstacle avoidance system etc. The central position drives the system as well as contains the processing unit containing microcontroller unit, wireless module and motor drivers. The end part contains four rotating probes of spring steel with embedded PVDF sensor.

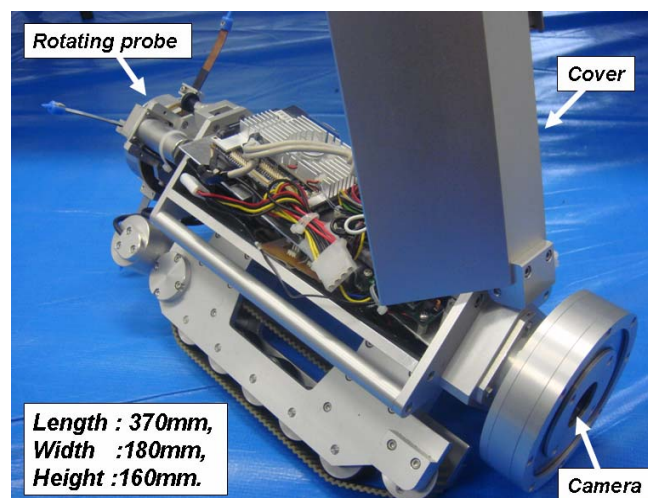


Fig. 2. Design of Pipe Crawler Robot.

The probe is positioned at the back of the robot. The rotating probe consisted of cantilever beam and PVDF film is fixed on the probe for the sensing as shown in Fig. 3. To control the cable of the rotating probe, a slip ring is used. The movement of the rotating probe is explained in the following section.

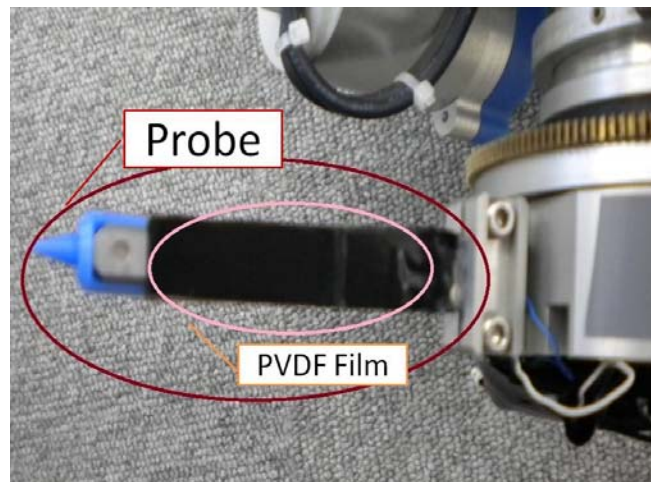


Fig. 3. Rotating probe with PVDF sensor.

4.1. Movement of the Rotating Probe

During tests, radius of the scanning tip is kept slightly less than that of the actual base radius of the tube. Therefore, the beam does not slip over the base surface. Whenever an obstacle comes in the way, the beam hits it, and starts bending, rubs over it and finally shoots out. The following series of figures (Figs.4 & 5.) give an idea as to how this process takes place.

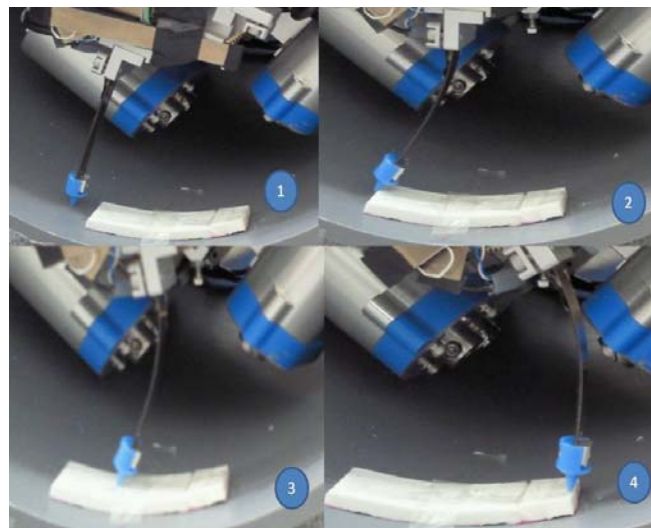


Fig. 4. Sequence of steps showing the beam going past a typical obstacle. (1) Free beam approaching defect of width 70 mm; (2) Beam starting to touch the defect; (3) Beam rubbing over the defect; (4) Beam about to shoot off.

The angular velocity of the stepper motor determines the rate at which the probe runs across the surface. Variation in the rate of scanning plays an important role when the strain is sensed by piezoelectric materials. Unlike strain gauges, piezoelectric materials are dynamic in nature i.e. the rate

at which they are strained strongly affects the nature and quality of signal that they produce. In the simplest form, a piezowafer may be compared to a capacitor that displaces charge upon actuation. Hence, faster/stronger actuation causes it to displace more charge and thus generate a stronger signal and vice-versa. However, the angular velocity of the stepper motor should not be very high otherwise it will not rub the surface of the defect.



Fig. 5. Test in PVC pipe of diameter 25 cm.

5. Rotating Probe in a PVC Pipe

PVDF generates a charge in response to a stress which can be converted to voltage and then amplified. PVDF generates an output in the range of pico coulombs with very high impedance. It needs to be transformed into a low impedance voltage signal, for processing the signal by standard measuring equipment. Charge amplifier is designed and implemented for this purpose.

To amplify the small voltage signal obtained by the charge amplifier we have used an amplifier, AD8607A, with a gain of 100. The voltage output of the PVDF is captured into the microcomputer by A/D converter. The main computer of the robot reads the data through serial transmission using an RS-232 cable. The sampling cycle of the A/D converter is 0.01 seconds. The set of experiments are performed to check the response of the PVDF film when the probe collides with the obstacles.

6. Experiments

All the experiments are performed on resting robot in a clean vinyl chloride pipe of 250 mm diameter, as shown in Fig. 5. To imitate hollow cylindrical tubes with growths, inside the cylinder, pieces of the rubber was fixed to create artificial projections. Experiments were performed with the setup as shown in Fig. 6. The height, width, and separation between projections are represented as h , b_p , and p_p respectively.

The response of the sensor when it is subjected to a projection of width 10 mm and height 3 mm, 6 mm and 10 mm respectively are shown in Fig 7-a,b and c.

The probe first touches the projection, then it bends, due to this bending which is shown in step 2 of Fig. 3; strain is developed in the probe. The PVDF sensor fixed on the probe senses this strain and gives voltage corresponding to the rate of change of strain, which is very high at the instant when the probe first touches the defect and thus a peak is observed in all the three experiments. After the impact it rubs the width of the defect and finally shoots out showing free vibrational response. When the probe touches the surface of projection (b_p), there is less voltage recorded. This is due to the fact that during that time there is less rate of change of strain developed on the probe because the bending of probe

almost remains the same when the probe first touched the surface of projection (shown in step 3 and 4 of Fig. 4). In all the three cases there is damping effect of vibration, this occurs when the probe shoot out of the projection.

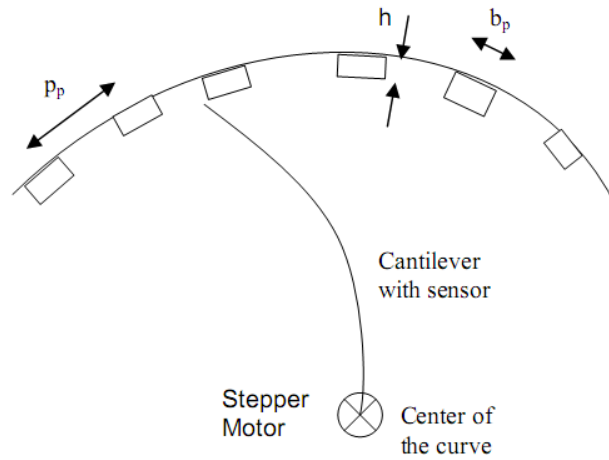


Fig. 6. A schematic of the moving cantilever probe against the obstruction.

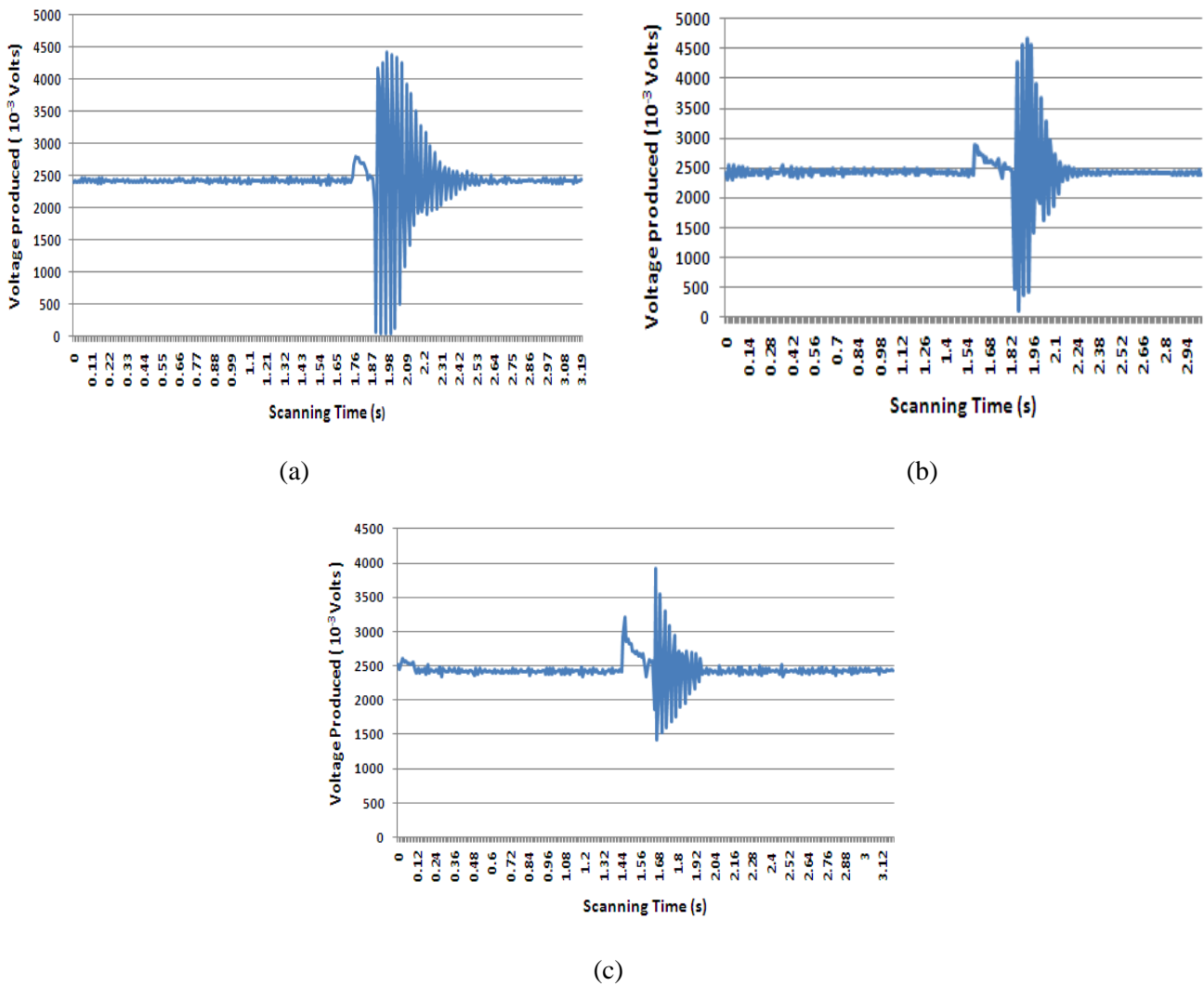


Fig. 7. Graph between voltage Vs. Scanning time for a projection of width 10 mm and height (a) 3mm; (b) 6mm; (c) 10mm.

It is observed that the voltage recorded at the instant when the probe first touches the defect is the highest at 10mm height. This is due to the reason that higher projection caused greater bending of probe and thus a higher initial strain is developed and due to that a high voltage is recorded. The vibration effect is the

highest in the case of 3mm projection because the higher height of the projection reduced the speed of the probe and thus after shooting off from the projection, it vibrates with less intensity.

The peak voltage recorded for different height projections is provided in Table 2.

Table 2. Peak voltage value corresponding to height of projection for a constant width of projection as 10 mm.

Height of Projection(in mm)	Peak Output Voltage(in mV)
3	2800
6	2873
10	3205

The response of the PVDF sensor when the probe rubs with projections of width 30 mm and 50 mm are shown in Figs.8-a and b. The height for both projections was kept constant as 10 mm.

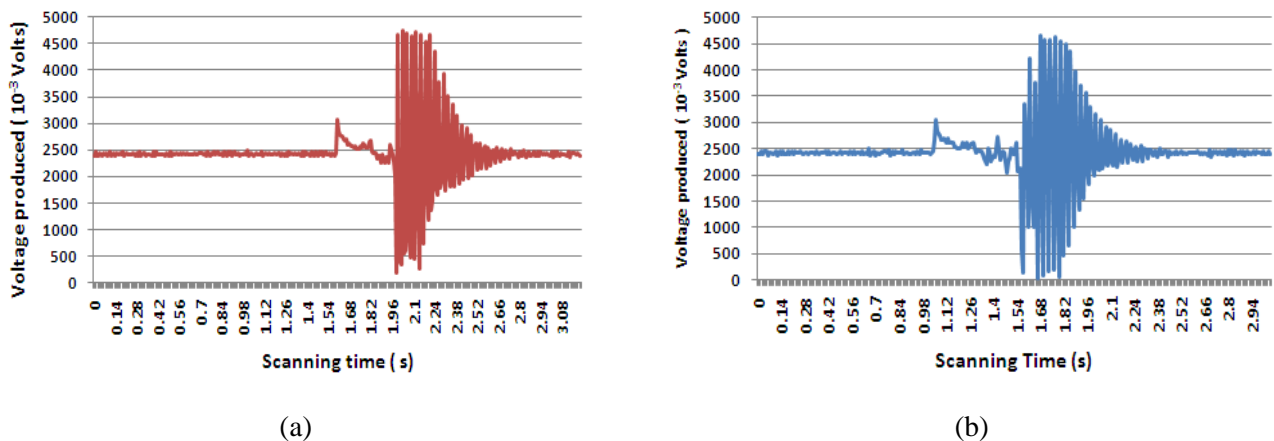


Fig. 8. Plot of Voltage vs. Scanning Time for projection of height 10 mm and (a) width 30 mm; (b) width 50 mm.

The change in width of the defect can be observed by observing the time elapsed between the instant when the first peak in voltage signal is recorded and the instant when the vibration effect starts. During that time duration, the probe rubbed the width of the projection. The recorded time instants of position when the first rise in voltage is observed (T_1) and start of vibration effect (T_2) are shown in Table 3. The difference of T_2 and T_1 is the time during which the probe rubbed the width of the projection and is denoted as T_3 .

The response of the probe when it is subjected to two projections in a rotation is studied next. Fig. 9-a presents the voltage produced by PVDF vs. Scanning time for two projection of height 5 mm and 10 mm, width same as 50 mm. Fig. 19-b presents the voltage output for width 50 mm and 30 mm, for a common height of 10 mm.

Table 3. Recorded time instants corresponding to width of projection for a constant height of projection as 10 mm.

Width(mm)	T ₁ (in sec)	T ₂ (in sec)	T ₃ (in sec)
10	1.45	1.56	0.11
30	1.60	1.99	0.39
50	1.06	1.55	0.49

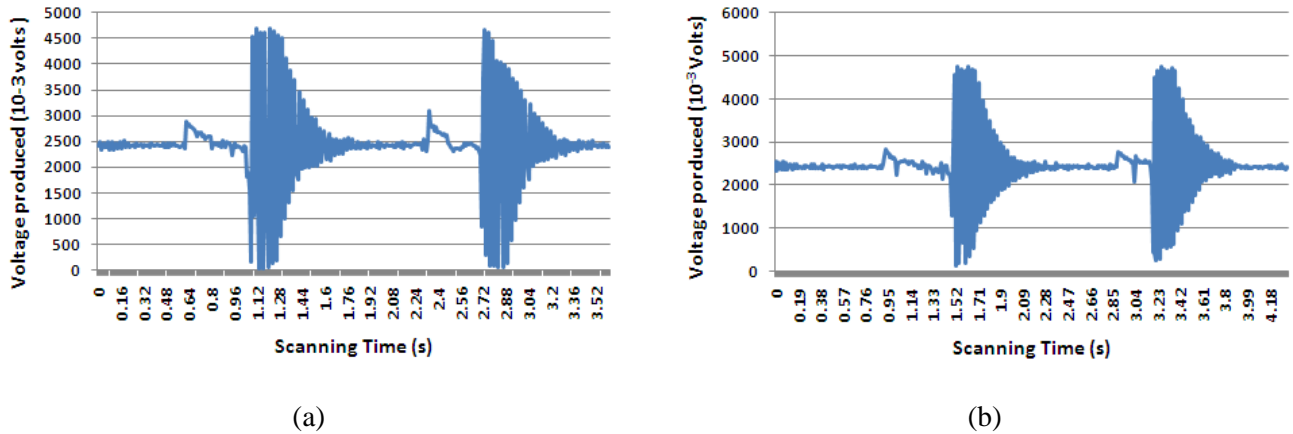


Fig. 9. (a) Voltage output for two projection of height 5 mm and 10 mm, width same as 50 mm; (b) Voltage output for two projection of width 50 mm and 10 mm, height same as 10 mm.

Fig. 10 presents the results of the PVDF sensor output when successively five projections of height 10 mm and width 10 mm were uniformly placed on the circumference of the pipe.

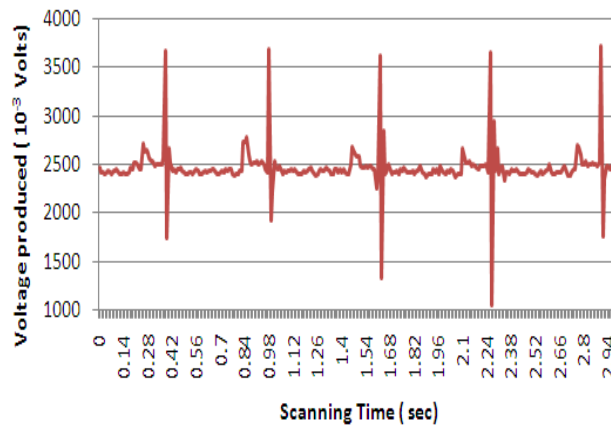


Fig. 10. Voltage output for five projections each of height 10 mm and width 10 mm.

It is observed from the Fig. 9-a that peak voltage due to defect of height 10 mm is greater than the defect of height 5 mm. This suggests that the height of the projection can be estimated by observing the peak voltage of the scanning results. In Fig. 9-b, it is shown that for the same height, when the width is increased, there is a time elapsed between the voltage peak observed due to bending and start of the vibration effect. This experiment suggests that the width of the projection can be estimated by observing this time elapsed. In Fig. 10, there is a pattern that repeats 5 times, this is because of the five projections on the surface of the pipe. The peaks are uniform as the projections were created at a uniform distance.

The response of the PVDF sensor is checked when it is subjected to projection of semicircle and triangular geometry. Fig. 11 shows the bending of probe for these experiments. Fig. 12-a presents the results of scanning with a projection of semicircle geometry with diameter 30 mm and Fig. 12-b presents for Equilateral triangle with side of 20 mm.

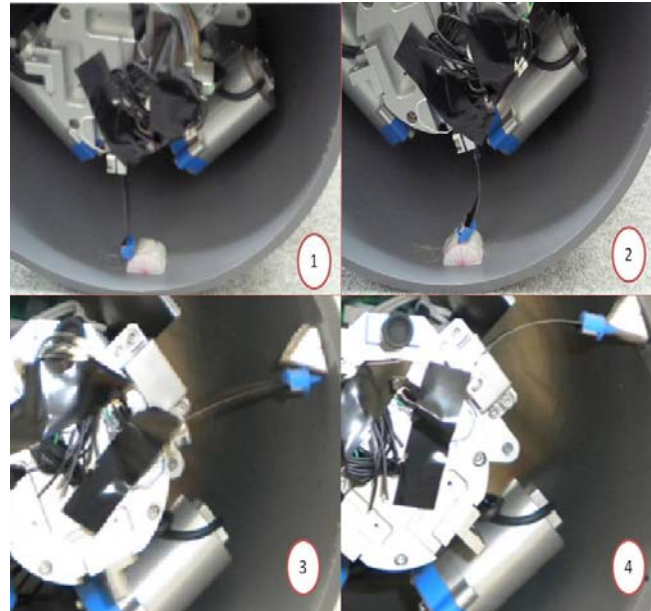
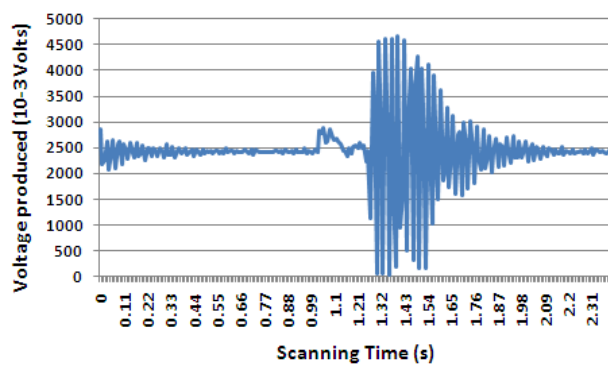
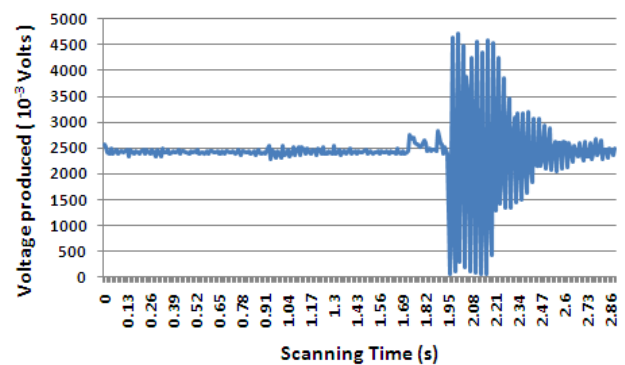


Fig. 11. (1) Probe touching the semicircle type projection; (2) Probe ready to shoot off from top of projection; (3) Probe touching the triangle type projection; (4) Probe ready to shoot off from top of projection.



(a)



(b)

Fig. 12. (a) Voltage output for projection of semicircle geometry of diameter 30 mm; (b) Voltage output for projection of Equilateral triangle with side of 20 mm.

Results shown in Fig. 13-a, b are pointing towards the property of PVDF sensor that it gives voltage proportional to rate of change of strain. When the probe rubbed the surface of a semicircle, due to change in surface, the probe experienced different bending and thus different strain and thus a plateau kind of structure is obtained before the vibration effect starts. In Fig. 13-b, when the probe rubbed the height of projection of triangle a voltage is produced at the very instant. Two peaks are observed before the vibration. The first one is obtained when the probe touched the projection for the first time and the other when the probe touched the top of the projection.

7. Conclusion

The present work provides a useful insight as to how, without using very sophisticated setups, a simple rotating probe with a PVDF film patch can be used as a fairly good sensor to sense finite sized projections in a pipe. The width, height and spacing of such projections are reliably predicted by the touch sensor. Further experiments can be carried out to check the response of the PVDF sensor with different angular speeds of the probe. The voltage obtained by PVDF sensor can also be calibrated in term of degree of roughness.

References

- [1]. Duran, O., Altheofer K., Seneviratne L. D., Laser Profiler model for robot based pipe inspection, *Automation Congress*, June 2009, pp. 353-358.
- [2]. Dongmei, W., Harutoshi, O., Yichun, Y., Katsumi, H., Takahiko, A. and Gunkichi, S., Pipe inspection robot using a wireless communication system, *Artificial Life Robotics*, Vol. 14, 2009, pp. 154–159.
- [3]. Beaulieu, L., Godin, M., Laroche, O., Tabard-Cossa, V. and Grutter, P., A complete analysis of the laser beam deflection systems used in cantilever-based systems, *Ultramicroscopy*, Vol. 107, Issues 4-5, April-May 2007.



sensors expo & conference

Pre-Conference: June 6, 2011
Conference & Expo: June 7-8, 2011
Donald E. Stephens Convention Center • Rosemont, Illinois

www.sensorsmag.com/sensorexpo

The Only Industry Event in North America Exclusively Focused on Sensors & Sensor Integrated Systems! Find the Solutions to Your Sensors & Sensing Technology Challenges!

Tuesday, June 7
9:00 AM – 10:00 AM

Opening Keynote: The New Era of Human 2.0: New Minds, New Bodies, New Identities
Dr. Hugh Herr
Biomechanics Researcher

Don't Miss these Expo Floor Highlights:

CO-LOCATED WITH:
Learn today, Design tomorrow.

ESC
MEMS PAVILION
ENERGY HARVESTING PAVILION
TECHNOLOGY UPDATE THEATER

SUBSCRIBERS:
Visit www.sensorsmag.com/sensorexpo to register or call 866-817-5048. Use discount code **A307E** for an EXTRA \$50 OFF a Gold or Main Conference Pass!

ASSOCIATION SPONSOR: IFSA
PRODUCED BY: QUESTEX MEDIA
OFFICIAL PUBLICATION: sensors

- [4]. Haw-Long, L., Win-Jin, C. and Yu-Ching, Y., Flexural sensitivity of a V-shaped cantilever of an atomic force microscope, *Materials Chemistry and Physics*, Vol. 92, Issues 2-3, 2007, pp. 438-442.
- [5]. Slangen, P., Leon, B., Christophede, V., Jean-Claude, G. and Yves, L., Digital Speckle Pattern Interferometry (DSPI) A Fast Procedure to Detect and Measure Vibration Mode Shapes, *Optics and Lasers in Engineering*, Vol. 25, Issues 4-5, 1996, pp. 311-321.
- [6]. Wai-On, W., Vibration Analysis by Laser Speckle Correlation, *Optics and Lasers in Engineering*, Vol. 28, Issue 4, 1997, pp. 277-286.
- [7]. Franco, R. A. and Ingram, K. J., A Very High Shock Data Recorder, *IEEE Transactions of the Southeastcon*, Vol. 1, 1991.
- [8]. Shirinov, A. V. and Schomburg, W. K., Pressure sensor from a PVDF film, *Sensors and Actuators: A Physical*, Vol. 142, Issue 1, 2008, pp. 48-55.
- [9]. Roger, V. and Stephen, C. G., Use of PVDF Strain Sensors for Health Monitoring of Bonded Composite Patches, *DSTO Aeronautical and Maritime Research Laboratory*.
- [10]. Gu, H., Zhao, Y. and Wang, M. L., A wireless smart PVDF sensor for structural health monitoring, *Structural control and Health Monitoring*, Vol. 12, 2005, pp. 329–343.
- [11]. Kuang, K. S. C., Quek, S. T., and Cantwell, W. J., Use of polymer-based sensors form monitoring the static and dynamic response of a cantilever composite beam, *Journal of Material Sciences*, Vol. 39, 2004, pp. 3839–3843.

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



The Third International Conference
on Bioinformatics, Biocomputational Systems and Biotechnologies

BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy



Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications

- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems

- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing

- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/BIOTECHNO11.html>



The Seventh International Conference
on Networking and Services

ICNS 2011

May 22-27, 2011 - Venice, Italy



Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/ICNS11.html>

Tracks:

- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks

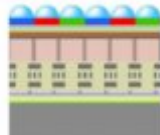
**CMOS Image Sensors
Technologies & Markets - 2010 Report**

**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



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 of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor 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. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

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/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 Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2011.pdf

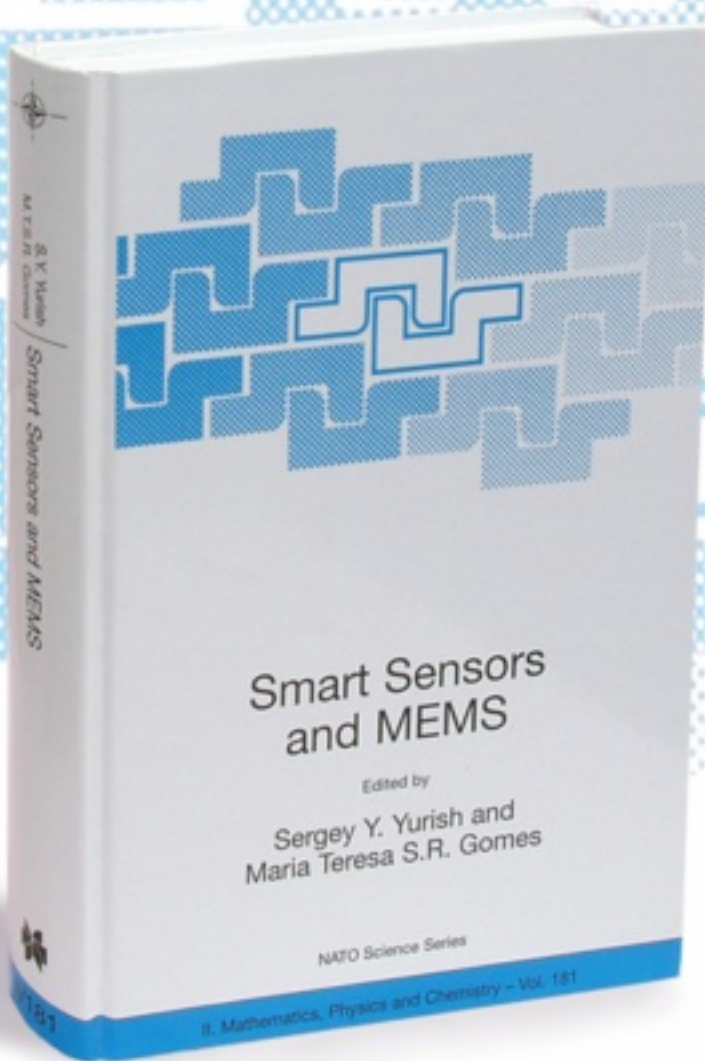
Smart Sensors and MEMS

Edited by

Sergey Y. Yurish and
Maria Teresa S.R. Gomes

The book provides an unique collection of contributions on latest achievements in sensors area and technologies that have made by eleven internationally recognized leading experts ...and gives an excellent opportunity to provide a systematic, in-depth treatment of the new and rapidly developing field of smart sensors and MEMS.

The volume is an excellent guide for practicing engineers, researchers and students interested in this crucial aspect of actual smart sensor design.



Kluwer Academic Publishers

Order online:

www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensors_and_MEMS.htm

www.sensorsportal.com