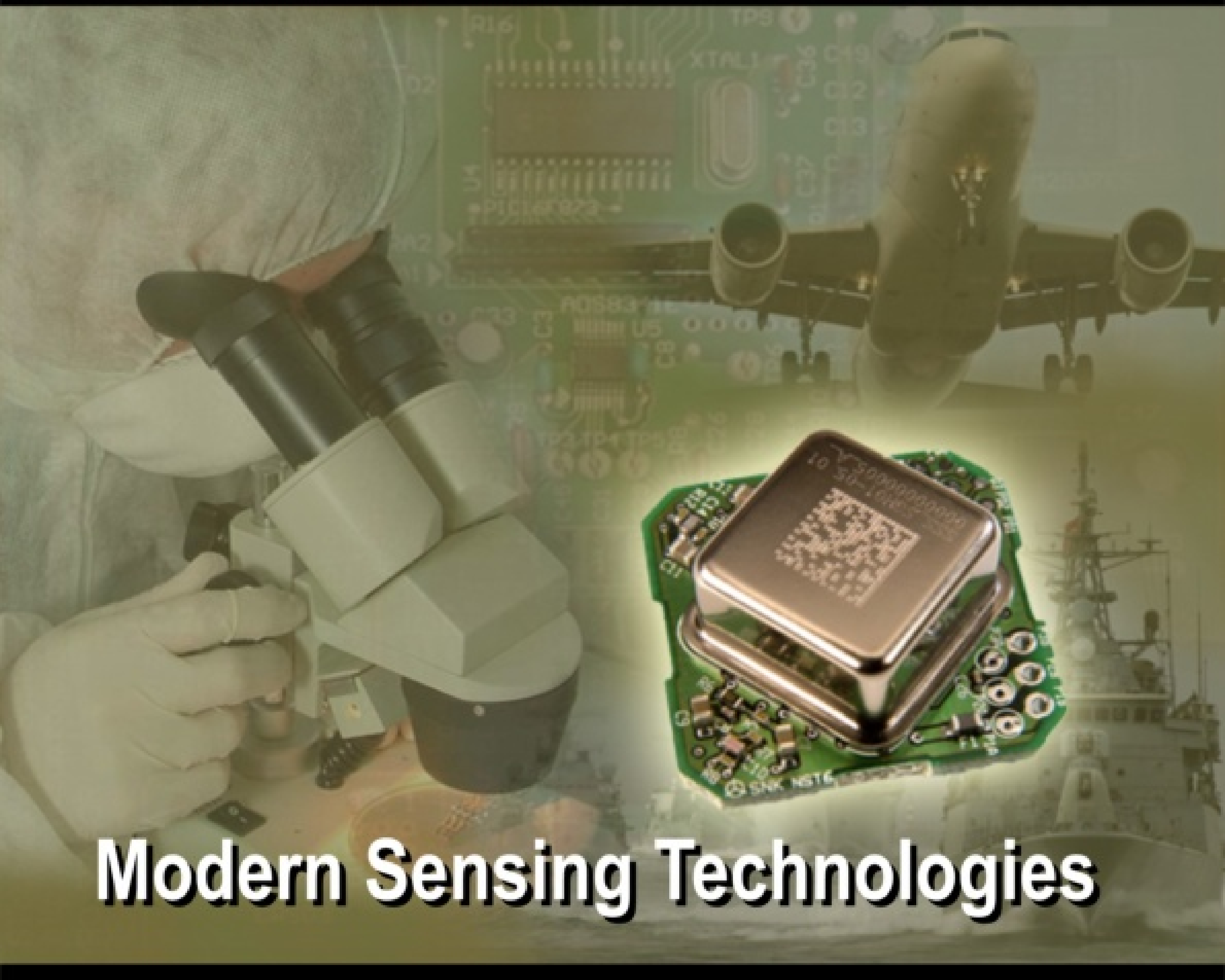
ISSN 1726-5749

SENSORS & TRANSDUCERS

vol. 90
Special
4/08



Modern Sensing Technologies

International Frequency Sensor Association Publishing

Sensors & Transducers

Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Editor-in-Chief: Sergey Y. Yurish
Guest Editors: Subhas Chandra Mukhopadhyay and Gourab Sen Gupta

Editors for Western Europe
Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Universitá di Brescia, Italy

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

Editor South America
Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe
Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia
Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Nothern 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, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
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
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
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, 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
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
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding Jian, Ning, Jiangsu 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, University 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
Hashsham, Syed, Michigan State University, USA
Hernandez, Alvaro, University of Alcala, 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
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA

Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Koh Young Technology, Inc., 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, DIMET, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mukhopadhyay, Subhas, Massey University, New Zealand
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucin, 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
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhbha 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 University 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
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., Northwestern University, 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 Institute 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
Vazques, 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 University 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
Ymeti, Aurel, University of Twente, Netherland
Yu, Haihu, Wuhan University of Technology, China
Yufera Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zeni, Luigi, Second University of Naples, Italy
Zhong, Haoxiang, Henan Normal University, China
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
Zhou, Zhi-Gang, Tsinghua University, China
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and CD-ROM. Copyright © 2008 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

Volume 90
Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Special Issue on Modern Sensing Technologies

Editorial

Sensors for Medical/Biological Applications

Wireless Sensors

Capacitive Sensors

Sensors Signal Processing

Gas Sensors

Image Sensors

Miscellaneous

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/Submition.htm

Sensors & Transducers Journal, Vol. 90, Special Issue, April 2008, pp. 100-116

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Resistive and Capacitive Based Sensing Technologies

[1]Winncy Y. Du and [2]Scott W. Yelich
[1]San Jose State University, San Jose, USA
[2]S&W Consultants, Santa Clara, USA
E-mail: winncy.du@sjsu.edu, swyelich@sbcglobal.net

Received: 15 October 2007 /Accepted: 20 February 2008 /Published: 15 April 2008

Abstract: Resistive and capacitive (RC) sensors are the most commonly used sensors. Their applications span homeland security, industry, environment, space, traffic control, home automation, aviation, and medicine. More than 30% of modern sensors are direct or indirect applications of the RC sensing principles. This paper reviews resistive and capacitive sensing technologies. The physical principles of resistive sensors are governed by several important laws and phenomena such as *Ohm's Law, Wiedemann-Franz Law*; *Photoconductive-*, *Piezoresistive-*, and *Thermoresistive Effects*. The applications of these principles are presented through a variety of examples including accelerometers, flame detectors, pressure/flow rate sensors, RTDs, hygristors, chemiresistors, and bio-impedance sensors. The capacitive sensors are described through their three configurations: parallel (flat), cylindrical (coaxial), and spherical (concentric). Each configuration is discussed with respect to its geometric structure, function, and application in various sensor designs. Capacitance sensor arrays are also presented in the paper. *Copyright © 2008 IFSA.*

Keywords: Resistive sensors, Capacitive sensors, Sensor arrays, Sensor design

1. 1. Introduction

This paper reviews the resistive and capacitive (RC) based measurement principles and their applications in sensing technologies. RC sensors apply a broad range of theories and phenomena from the fields of physics, material science, biology, electrochemistry, and electronics [1, 2].

Resistive sensors have assisted mankind in analyzing, controlling, and monitoring thousands of functions for over a century. Some milestones in the development of resistive sensors include the discovery of the *Piezoresistive Effect* by Lord Kelvin in 1856, the use of platinum as the element of a resistance thermometer by Sir William Siemens in 1871, the invention of a *Carbon Track*

Potentiometer by Thomas Edison in 1872, and the patenting of a non-linear *rheostat* by Mary Hallock-Greenewalt in 1920. In automobiles, resistive sensors are used to measure air flow rate, throttle position, coolant/air temperature, oxygen volume, wheel speed, and so forth. In airplanes, highly reliable resistive sensors monitor engine functions, hydraulic systems, electronic devices, temperature and pressure readings, and have greatly increased aircraft safety. Measuring and analyzing electrical impedance characteristics of the human body have allowed doctors to diagnose certain diseases, monitor health conditions, and analyze the treatment results. The advantages of resistive sensors are their reliability, simple construction, adjustable resolution, and maintenance-free technology. Electrical resistance is also the easiest electrical property to measure precisely over a wide range at moderate cost. These important features have often made resistive sensors the preferred choice in sensor designs.

Capacitive sensors are traditionally divided into two basic classifications: *passive* or *active*, based on whether or not there are any electronic components in the sensor. Passive sensors do not have any electronics in the sensor, thus minimizing guard size. Passive sensors have some significant advantages: they have greater flexibility in probe configuration, are more stable, and cost less than active systems. Their disadvantages include lower bandwidth and lower drive frequency, which makes them unsuitable for some applications. Active sensors have electronics, usually a small circuit board, packaged inside the sensors. Active sensors operate at much higher frequencies and bandwidths, and are particularly well suited to applications which may involve stray electrical noise on the target. Their disadvantages include higher costs and less configuration flexibility [3]. Capacitive sensors are the most precise of all electrical sensors and are known for their extremely high sensitivity, high resolution, high bandwidth, robustness, stability, and drift-free measurement capability. Capacitive sensors can be used in a wide range of applications including: precision movement detection, coating thickness gauging, liquid level and flow rate monitoring, diamond turning, chemical element selection, biocell recognition, and aircraft engine rotational alignment. They can also be used in severe environments (high temperature, magnetic fields, and radiation) and in non-contact and non-intrusive applications.

The progress in micro- and nano-machining technologies have significantly advanced traditional resistive and capacitive transducers to a new level – high sensitivity, low power consumption, rapid response time, and miniaturization. Resistance and capacitance sensing principles can also be combined with other sensing technologies, such as ultrasonic, RF, CMOS, or fiber-optics, to create more sophisticated and powerful hybrid sensors.

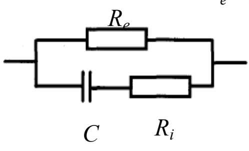
This paper is organized as follows: Section 1 is an introduction; Section 2 overviews the principles, design, and application of resistive sensors; Section 3 presents the classification, principles, design, and application of capacitive sensors; and Section 4 gives the summary.

2. Resistive Sensing Technologies

2.1. Principles

Resistive sensors are used to monitor physical or chemical parameters that can induce a change in electrical resistance. The magnitude of the physical or chemical parameter, such as light, strain, voltage, magnetic field, or gas/liquid concentration, can be inferred from the measured resistance value. The basic physical principles behind resistive sensors are summarized in Table 2.1.

Table 2.1. Basic Physical Principles of Resistive Sensors.

Ohm's Law: The resistivity R (or conductivity $1/R$) of a material passing electric current I under an applied voltage V is: $R = \frac{V}{I}$ (2.1)	The electrical resistance is a function of both its physical geometry and the resistivity of the material: $R = \rho \frac{l}{a}$ (2.2) l – length; ρ – specific resistivity of the material; a – cross sectional area.
Photoconductive Effect: When light strikes certain materials, the resistance of the material decreases. For instance, the conductance of a semiconductor is described by: $\Delta\sigma = en(\mu_n \tau_n + \mu_p \tau_p)$ (2.3) μ_n, μ_p – free-electron and hole movement; τ_n, τ_p – free-electron and hole lives; e – charge of an electron; n – number of generated carriers per second per unit of volume.	*Piezoresistive Effect*: Resistance changes when the material is mechanically deformed. The sensitivity of resistance with respect to wire elongation dl is: $\frac{dR}{dl} = 2\frac{\rho}{v} l$ (2.4) ρ – specific resistivity of the material; l – conductor's length before deformation; v – volume of the material.
Wiedemann-Franz Law: The ratio of the thermal conductivity to the electrical conductivity of a material is proportional to its absolute temperature. $K / \sigma = LT$ (2.5) K – thermal conductivity; σ – electrical conductivity; L – proportionality constant (*Lorenz Number*); T – absolute temperature.	*Thermoresistive Effect of Metals*: The electrical resistance of a metal conductor increases as the temperature increases. The relationship between temperature and resistance is: $R(t) = R_0 \left[1 + \alpha(t - t_0) + \beta(t - t_0)^2 + \gamma(t - t_0)^3 + \ldots\right]$ A simplified version of the above equation is: $R(t) = R_0 [1 + \alpha(t - t_0)]$ (2.6) R_0 – resistance at the reference temperature t_0 (usually either 0°C or 25°C); α, β, γ – temperature coefficients.
Thermoresistive Effect of Semiconductor Materials: Electrical resistance of semiconductor materials decreases with increasing temperature. The relationship between electrical resistance and temperature is exponential: $R(t) = R_0 e^{\left[\beta\left(\frac{1}{t} - \frac{1}{t_0}\right)\right]}$ (2.7) R_0 – resistance at the reference temperature t_0 (usually either 0°C or 25°C); β – temperature coefficient.	*Bioimpedance Model*: Electrical properties of the human body can be characterized by a three-element equivalent electrical model as shown in the Figure. Impedance of the human body Z is [4]: $Z = R_e // (Z_c + R_i) = R_e // (\frac{1}{j\omega C} + R_i)$ (2.8)  R_e: extracellular liquid resistance R_i: intracellular liquid resistance C: cell membrane capacitance

2.2. Design and Applications

Potentiometric Sensors

A potentiometer (or *pot*) relates a change in length to a resistance change. The resistance of a pot can be varied by the position of a movable contact on a fixed resistor, which can be either linear or circular in shape. Pots are commonly used as a linear or angular position sensor, air flow meter, wind direction detector, or volume and tone control in stereo equipment. Fig. 2.1 shows a potentiometric type of pressure sensor designed by *SFIM SAGEM,* France. It has three terminals: a power input, a ground and a variable voltage output. When the pressure of an input liquid or gas expands the diaphragm, the wiper connected to the diaphragm will slide along the potentiometer. The location of the wiper is determined by the magnitude of the pressure.

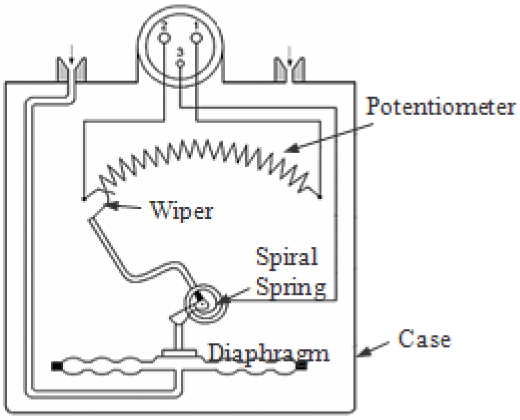


Fig. 2.1. A Potentiometric Pressure Sensor.

The advantages of potentiometers are their high output signal level (no need for an amplifier), low cost, and adaptability to many applications. Disadvantages include their high hysteresis and sensitivity to vibration.

Photoresistive Sensors

A photoresistive sensor utilizes the principles of a photoresistor – an electronic component whose resistance decreases with increasing incident light intensity. A photoresistor, often referred to as a *light-dependent resistor*, *photoconductor*, or *photocell*, is made of a high-resistance semiconductor material. If light reaching the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance. The semiconductor cadmium sulfide (CdS) is most sensitive to visible light, while lead selenide (PbSe) is most efficient in near-infrared light. A practical application of a photoresistor is to detect flames.

Fig. 2.2 shows a flame detector comprised of an ultraviolet (UV) sensitive photoresistor (cathode) and an anode [5]. When UV light from a flame is present in front of the UV sensitive photocathode, the voltage across the photocathode and the anode will force photoelectrons emitted from the photocathode to move towards the anode. A readout circuit detects this resistance change due to the presence of the flame.

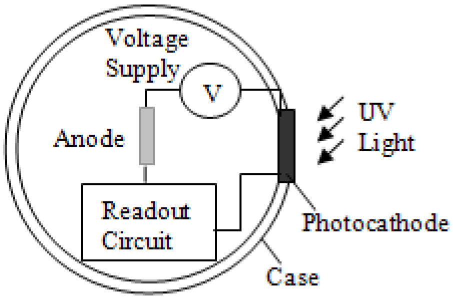


Fig. 2.2. Schematic of a UV Flame Detector.

Photoresistors are generally inexpensive. Their small size and ease of use make them popular in many applications, e.g., detecting fires, turning street lights on and off automatically according to the level of daylight, reading inventory bar codes, sensing motion, and measuring light intensity.

Piezoresistive Sensors

Piezoresistive sensors are designed based on a materials' piezoresistivity – defined as a change in electrical resistance of the material due to its mechanical deformation. Piezoresistive sensors are commonly used to measure force, pressure, acceleration, vibration, and impact. Piezoresistive accelerometers have an advantage over piezoelectric accelerometers in that they can measure accelerations down to zero Hz. They have good high frequency response with relatively low voltage output and high performance. However, their output signals are easily affected by temperature variations and noise, thus compensation circuits are often required to correct sensor errors. Fig. 2.3 illustrates a catheter based medical device for intravascular blood pressure measurement [6]. Its diaphragm consists of a force transducing beam and a piezoresistor. The sensor chip is ultra-miniaturized (0.1mmx0.14mmx1.3mm).

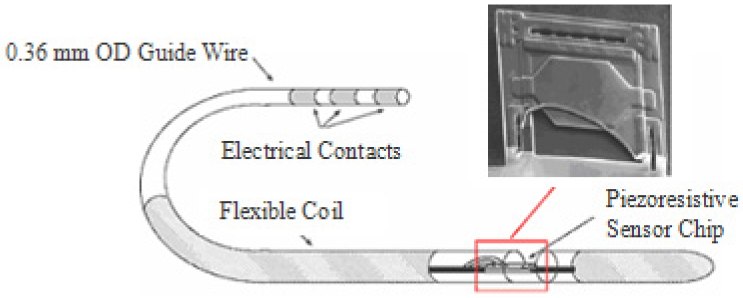


Fig. 2.3. A Piezoresistive Blood Pressure Sensor.

Thermoresistive Sensors

Resistance-based temperature sensing devices include *Resistance Temperature Detectors* (*RTDs*) and *Thermistors*. RTDs are positive temperature coefficient sensors whose resistance increases with temperature. RTDs are constructed in *wire-wound* and *thin film* types (Fig. 2.4). The former is made by winding a very fine metal wire around an inert substrate (glass or ceramic). The latter is produced through *Thin Film Technology* or *Thin Film Lithography* that deposits a thin film of metal (e.g., 1 µm Platinum) onto a ceramic substrate through cathodic atomization or "sputtering".

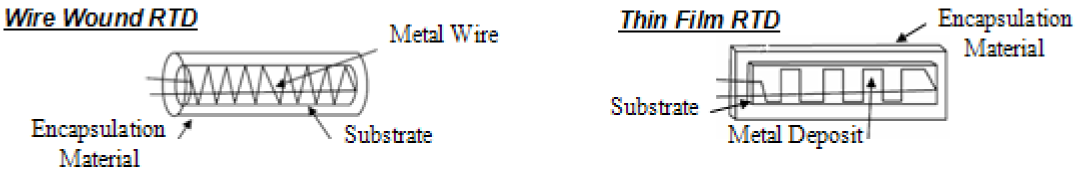


Fig. 2.4. Two Types of RTD Construction [7].

The primary metals in use are platinum, copper, and nickel, because they: (1) are available in near pure form, ensuring consistency in the manufacturing process; (2) have a very predictable, near linear temperature versus resistance relationship; and (3) can be processed into extremely fine wire. This is important especially in “wire wound” elements -- the most common types of RTDs. RTDs are typically used for temperatures not exceeding 850°C. Although slower in response than thermocouples, RTD sensors offer several advantages in industrial applications. They are especially recognized for excellent linearity throughout their temperature range (typically from -200 to +850 ^{o}C) with a high degree of accuracy, robustness, stability and repeatability. For a typical Platinum RTD, stability is rated at ±0.5° C per year.

Thermistors (from the words ***therm**al* and res***istor***) are made from semiconductor materials whose resistance decreases with increasing temperature – thus they are called *negative* temperature coefficient sensors. Due to their nonlinearity and exponential nature (Eq. 2.7), thermistors are limited to temperature measurements of less than 200°C. Although Eq. 2.7 can be linearized, it generally cannot meet accuracy and linearity requirements over larger measurement spans. Their drift under alternating temperatures is also larger than RTD’s. Thermistors are quite fragile and great care must be taken to mount them so that they are not exposed to shock or vibration. Thermistors have not gained the popularity of RTDs or thermocouples in industry due to their limited temperature range. Compared to wire-wound RTDs and thermocouples, thermistors are less expensive and much smaller in size. They also have a faster response, lower thermal mass, simpler electronic circuitry, and exhibit better sensitivity. A thermoanemometer for flow rate measurement is shown in Fig. 2.5. Two thermistors (R_0 and R_s) are immersed into a moving medium. R_0 measures the initial temperature of the flowing medium. A heater, located between R_0 and $R_{s,}$ warms the medium and its temperature is then measured by R_s. The flow rate ΔQ can be derived for the medium based on the temperature difference (T_s-T_0) attained (*King’s Law*) [8]:

$$\Delta Q = kl\left(1+\sqrt{\frac{2\pi\rho c d v}{K}}\right)(T_s - T_0), \qquad (2.9)$$

where K, c – thermal conductivity and specific heat of fluid at a given pressure; ρ – fluid density; l, d – length and diameter of the sensor; T_s, T_0 – surface temperature of sensor R_s and R_0; v – velocity of the medium.

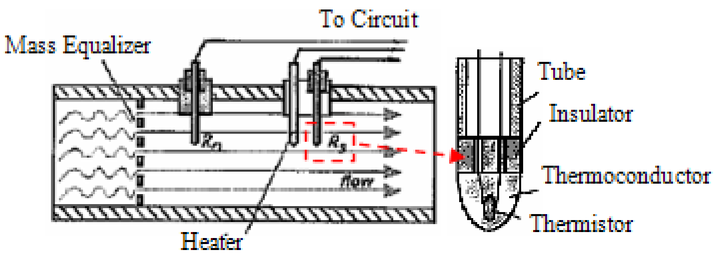


Fig. 2.5. A Thermoanemometer [5].

Resistive Humidity Sensors (Hygristors)

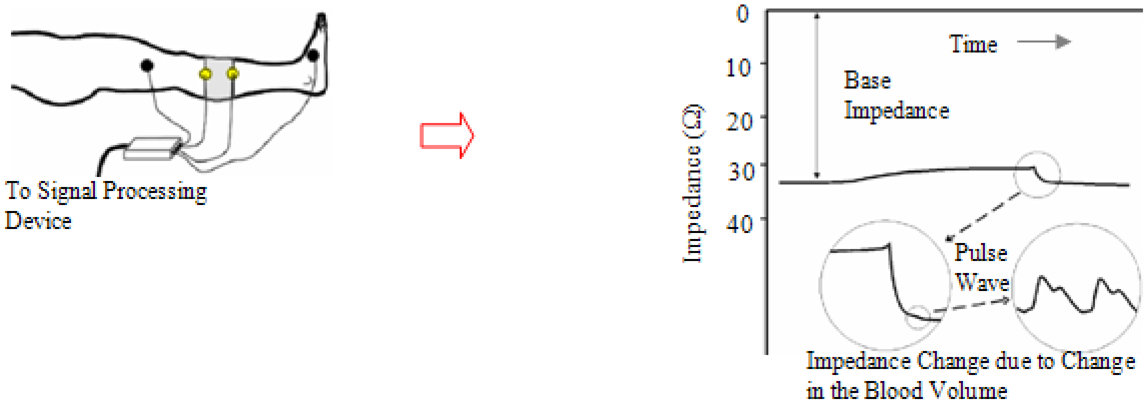
Resistive humidity sensors measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt, or treated substrate. The specific resistivity of a hygroscopic material is strongly influenced by the concentration of absorbed water molecules. Its impedance change is typically an inverse exponential relationship to humidity. A typical hygristor (a contraction of *hygro-*

and *resistor*) consists of a substrate and two silkscreen-printed conductive electrodes. The substrate surface is coated with a conductive polymer/ceramic binder mixture, and the sensor is installed in a plastic housing with a dust filter (Fig. 2.6).

Fig. 2.6. Resistive Humidity Sensors.

Bioimpedance Sensors

Bioimpedance sensors can extract biomedical information relative to physiology and pathology of the human body based on the electrical properties of tissue and organs. Usually, a small AC current or voltage is applied to an electrode system placed on the surface of the body to measure the relative impedance of tissue and organs. A German company, *medis*. Medizinische *Messtechnik GmbH*, has used an impedance method to measure changes in venous blood volume as well as pulsation of the arteries. As blood volume changes, the electrical impedance also changes proportionally. This impedance can be measured by passing a small amount of high frequency AC current through the body. The measurement requires four electrodes as shown in Fig. 2.7a. The two middle electrodes detect a voltage, and their placement defines the measurement segment. The outer electrodes are used to emit a small current required to measure the impedance. The placement of these outer electrodes is not critical. This method allows doctors to detect blood flow disorders, early stage arterioscleroses, functional blood flow disturbances, deep venous thromboses, migranes, and general arterial blood flow disturbances. Fig. 2.7b shows a typical measurement result using this method. Electrical bioimpedance sensing devices are safe, non-invasive, inexpensive, and easy to operate.



(a) (b)

Fig. 2.7. Bioimpedance Measurement.

Zetek Inc. (Aurora, Colorado) developed the *CUE Fertility Monitor*. It consists of a hand-held digital monitor and oral and vaginal sensors (Fig. 2.8). The sensors detect and record the electrical resistance and ionic concentration change of saliva and vaginal secretions, in response to the cyclical changes in estrogen. The CUE monitor is claimed to both predict and confirm ovulation. The peak electrical resistance in the saliva occurs 5~7 days before ovulation, and the lowest electrical resistance in cervical secretions occurs about a day before ovulation.

Fig. 2.8. A CUE Fertility Monitor.

Resistance-Based Chemical Sensors

Resistance chemical sensors measure the change in electrical conductivity of a sensing layer resulting from the interaction between the sensing layer and a chemical analyte. Materials used in these sensors are semiconductors such as metal oxides, organic macro-molecule-metal complexes, conducting polymers and carbon black-polymer blends. A classical example is the tin oxide based gas sensor. The tin oxide sensing layer is first activated by heating to >2500°C to form a depletion layer where oxygen is chemisorbed on the surface. The conductivity of the activated sensor may be increased or decreased depending on the nature of the incoming gases. Reducing gases increase the conductivity and oxidizing gases decrease the conductivity of the sensor. The advantages of these semiconductor-based sensors are: easy fabrication (by sputtering), simple operation and low cost. The main disadvantages are their high-energy requirements and low selectivity. Recent research and development efforts have focused on increasing their energy efficiency and improving their selectivity. Hence, materials that operate at ambient temperature, such as conducting polymers and carbon black-polymer blends, have been extensively investigated. The array sensing approach combined with statistical algorithms, such as cluster analysis and principal component analysis, greatly improves the selectivity of this sensing technique.

Fig. 2.9 shows a catalytic gas sensor (pellistor). It consists of a very fine coil of wire suspended between two posts. The coil is embedded in a pellet of a ceramic material, and on the surface of the pellet (or 'bead') there is a special catalyst layer. In operation, current is passed through the coil, which heats up the bead to a high temperature.

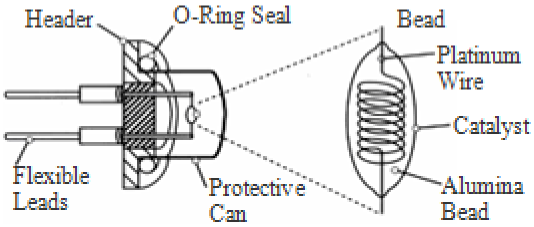


Fig. 2.9. A Pellistor.

When a gas molecule comes into contact with the catalyst layer, the gas 'burns' and heat is released which increases the temperature of the bead. This temperature rise causes the electrical resistance of the coil to increase.

A more versatile sensing system is based on the carbon black-polymer blend where the carbon particles give the electrical conductivity and the polymer provides the sensor function. The sensor response is a result of the polymer swelling, which causes the conductivity of the sensor to change. The main advantages of using carbon black-polymer blends as a sensing layer are that the sensor is reusable and the selectivity can be tailored by choosing polymers with desired functionalities. Fig. 2.10 shows a chemiresistor formed by depositing a thin film of non-conductive polymer, infused with carbon black particles, onto the metallic inter-digitated electrodes of a glass chip. The absorption of certain chemical vapor results in a measurable decrease in the electrical conductance of the sensing element. Such sensors are inexpensive and easily mass-produced. A potential commercial application for this sensing technique could be a system for detecting illegal drugs [9].

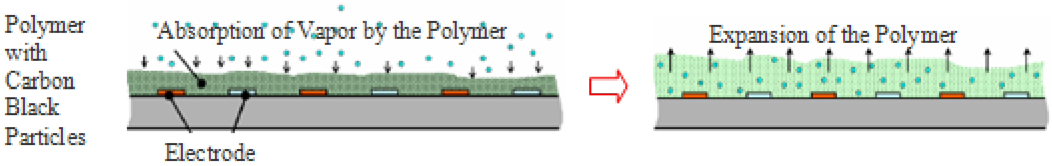


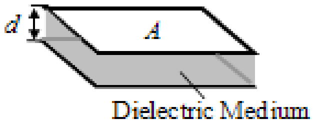
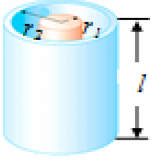
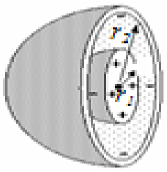
Fig. 2.10. Operation of a Chemiresistor.

3. Capacitive Sensing Technologies

3.1. Types of Capacitive Sensors

At the heart of any capacitive-sensing system is a capacitor. Capacitors are available in three configurations: flat (parallel), cylindrical (coaxial), and spherical (concentric), as shown in Table 3.1. All capacitive sensors fall into one of these three design classifications, with the flat and cylindrical being the most commonly used forms.

Table 3.1. Capacitance & Capacitor Configurations.

Flat (Parallel) Capacitor: $C=\frac{\varepsilon_r\varepsilon_0 A}{d}$	Cylindrical (Coaxial) Capacitor:	Spherical (Concentric) Capacitor:
(3.1)  d A Dielectric Medium	 r_2 r_1 l $C=\frac{2\pi\varepsilon_r\varepsilon_0 l}{\ln(r_2/r_1)}$ $(l>>r_2)$ (3.2)	 r_2 r_1 $C=\frac{4\pi\varepsilon_r\varepsilon_0 r_1 r_2}{r_2-r_1}$ (3.3)

In the table, ε_r is the relative permittivity of the medium between the electrodes: ε_0 is the permittivity of a vacuum. The ratios A/d, $2\pi l/[\ln(r_2/r_1)]$, or $4\pi r_1 r_2/(r_2-r_1)$ are the *geometry factors* for a parallel-plate capacitor, a coaxial capacitor, and a spherical capacitor respectively. Eqs. 3.1-3.3 describe the relationship between capacitance and the dielectric constants (ε_r, ε_0) as well as the geometric parameters (A, d, l, r_1, r_2). Varying any of these components will change the capacitance, which then can be accurately measured and thus defines the operating principle of capacitive sensors. Advantages of capacitive sensors are their simple structures, high sensitivity, high resolution, temperature resistance, long-term stability, and durability. Some capacitive sensors can achieve sub-nanometer position resolution (<0.01nm), having a bandwidth to 100 kHz. Capacitive sensors can provide contact or noncontact measurement of various physical or chemical quantities representing distance, position, acceleration, separation, proximity, force, pressure, biocells, chemical substances, and particles.

3.2. Design and Applications

Parallel Capacitor-based Sensors

The majority of capacitive sensors use the parallel-plate configuration. The sensing principle of such sensors is based on a capacitance change due to a change in one or more of the following (refer to Fig. 3.1): (1) the distance between two plates; (2) the area of overlap between two plates; (3) the dielectric constant; (4) the conductivity of the plate(s).

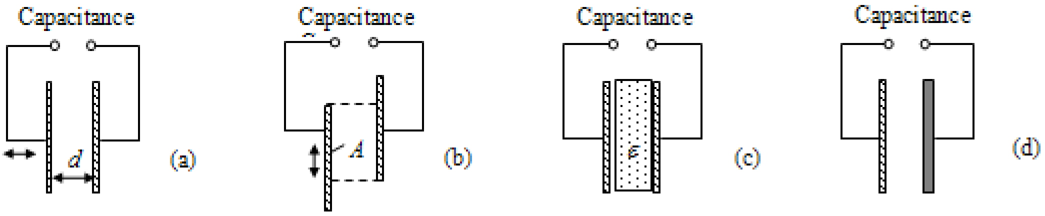


Fig. 3.1. Capacitance Varies with Distance, Area, Dielectric Constant, and Electrode Conductivity.

Parallel capacitive sensors are either single or dual-plate design. In a single plate (or electrode) design, the target – a conductive object, functions as the second electrode (Fig. 3.2a); while in the dual-plate design (Fig. 3.2b), the target – a non-conductive (or very low conductivity) object, serves to vary the amount of electric flux reaching the second electrode.

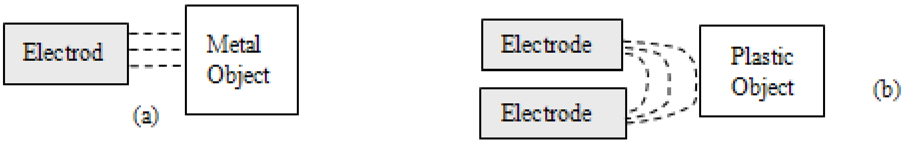
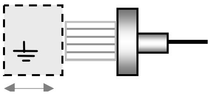
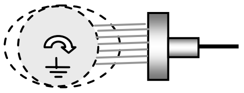
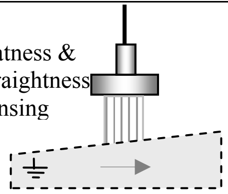
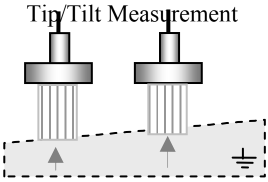
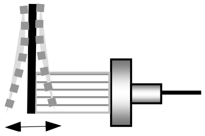
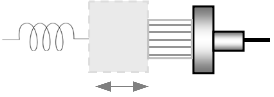
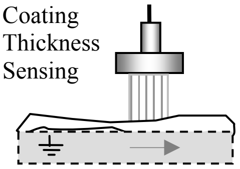
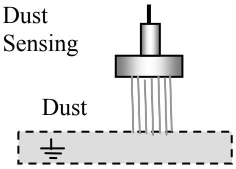


Fig. 3.2. Single-Electrode and Dual-Electrode Design.

Parallel capacitive sensors can detect motion, distance, acceleration, fluid level, biocells, and chemicals. Some of these applications are summarized in Table 3.2. Parallel capacitive sensors can also be designed to measure pressure; such sensors are relatively robust compared to other types of pressure sensors. A capacitance variation can be obtained when a pressure acts on one of the parameters modifying the electric field between two electrodes of a capacitor.

Fig. 3.3a shows a capacitive pressure sensor (*VEGA Technique*, France). One of its electrodes is connected to a sensing diaphragm. The unit forms a capacitor whose variation in capacitance is determined by the displacement of the diaphragm. In this case, the variable parameter of capacitance C is the surface area A of the plates, and A itself is a linear function of the displacement l. An alternative design of a pressure sensor is to measure the variation of distance d between two plates (see Fig. 3.3b).

Table 3.2. Applications of Parallel Capacitive Sensors.

 Displacement Sensing	 Out-of-Plane, Out-of-Round Measurement	 Flatness & Straightness Sensing	 Tip/Tilt Measurement
 Vibration Sensing	 Force Measurement	 Coating Thickness Sensing	 Dust Sensing Dust

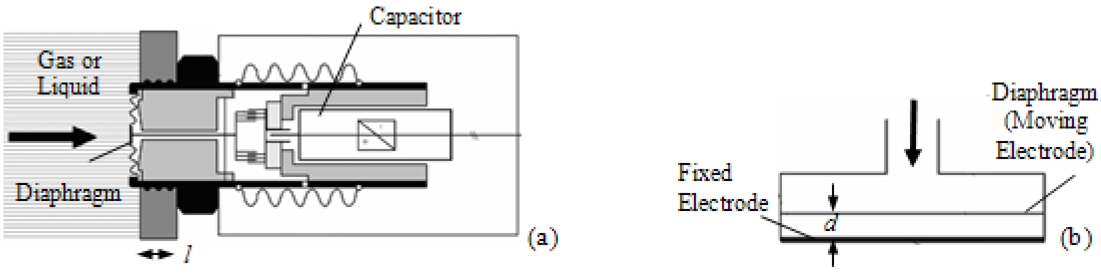
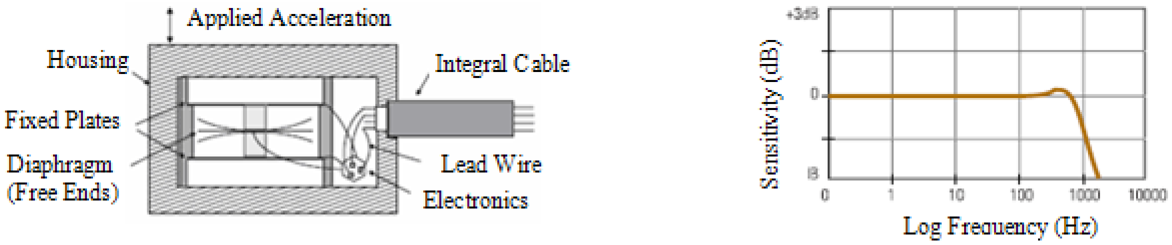


Fig. 3.3. Capacitive Pressure Sensors: (a) with *A* Variation; (b) with *d* Variation.

If one plate of a parallel capacitor moves with respect to acceleration or vibration, a capacitive accelerometer is formed. Fig. 3.4a shows a *PCB Piezotronics* capacitive accelerometer. It contains a diaphragm, which acts as a mass undergoing flexure in the presence of acceleration. Two plates sandwich the diaphragm, creating two capacitors, each with an individual fixed plate and each sharing the diaphragm as a movable plate. The flexure causes a capacitance shift by altering the distance between the two parallel plates. The two capacitance values are sent to a bridge circuit, and the electrical output varies with input acceleration. Such a design can achieve true DC response and high performance for uniform acceleration and low-frequency vibration measurement as shown in Fig. 3.4b.



(a) (b)

Fig. 3.4. Typical Element Structure of a Capacitive Accelerometer (a) and its Response (b).

Capacitive sensor designs based on variation of the dielectric constant are often found in humidity, force/pressure, chemical-substance, and biocell sensing applications. Fig. 3.5 illustrates the mechanism of a pellicular sensor developed by *ONERA French Aerospace Lab*. The sensor detects a change in relative permittivity of the dielectric ε_r between two electrodes when a force or pressure is exerted on the plates. This sensor is very thin (about 80μm) and can measure micro-pressure. Advantages of such pellicular sensors are their compactness, resistance to vibration, and high bandwidth (50~200 kHz). The primary disadvantage is that they are temperature sensitive.

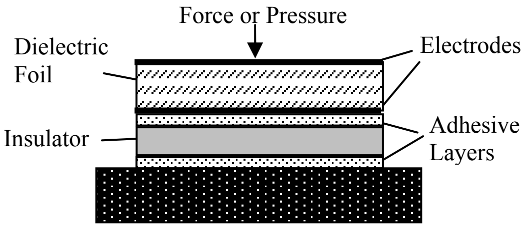


Fig. 3.5. Schematic of a Pellicular Sensor.

A chemical sensor designed at *Biose State University* [10] utilizes a variable capacitor composed of two electrodes separated by a chemically sensitive polymer (Fig. 3.6). The polymer will absorb specific (target) chemicals (analytes). Upon analyte absorption, the polymer swells and increases not only the distance between the two electrodes, but also the polymer's dielectric permittivity. These changes alter the capacitance of the device and can be electrically detected and measured.

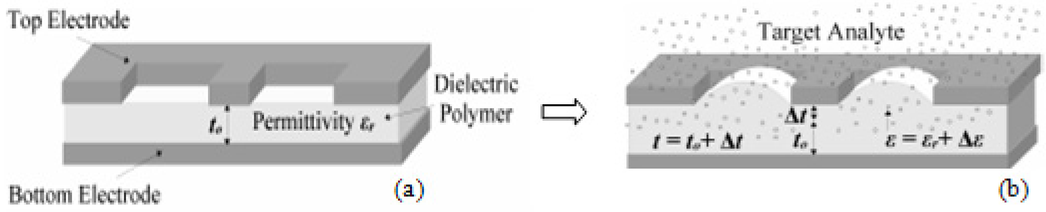


Fig. 3.6. A Capacitive Chemical Sensor.

Researchers at *University of Illinois at Urbana-Champaign* designed a collapsible capacitive tactile sensor that uses soft conductive elastomers as electrodes instead of traditional hard materials [11]. By constructing the electrodes from a soft conductive elastomer, this MEMS capacitive device exhibited flexibility and unprecedented robustness. To increase the capacitance of the sensor, they used a large electrode area and a small electrode gap (2.4μm). This was achieved by inserting a conductive poly-dimethylsiloxane sheet with a regular array of small pillars between the electrodes, shown in Fig. 3.7 and Fig. 3.8. The pillars not only define the air gap, but also supply the restoring force to separate the electrodes.

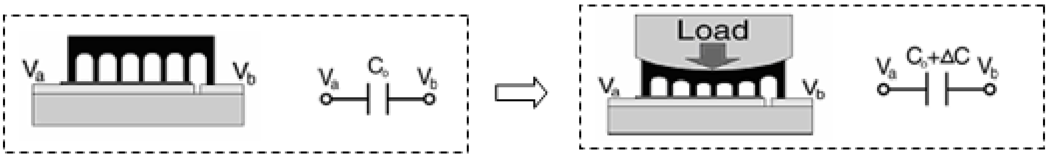


Fig. 3.7. Schematic of the Collapsible Capacitive Sensor Operation.

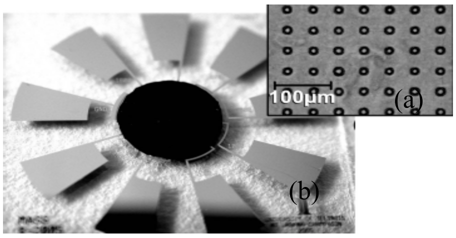


Fig. 3.8. (a) Flexible Conductor Capacitive Tactile Sensor; (b) Micrograph of Support Pillar Array Built into Flexible Conductor.

Well-designed electrodes of capacitive sensors also allow scientists and researchers to analyze deoxyribonucleic acid (DNA) for applications in medicine and biology. A label-free capacitive DNA sensing algorithm has been developed at *University of Bologna* in Italy [12]. In this method the electrode-solution interfaces are characterized by capacitive parameters sensitive to the state of the electrode surface. DNA targets in the solution bond with the probe and affect the value of interface electrical capacitance, this variation is then measured by accurate instruments. Advantages of this method over the conventional optical marker are: (1) no need for an expensive optical reading device; (2) real-time detection; and (3) improved sensitivity.

Coaxial Capacitor-based Sensors

The coaxial configuration is the second most popular design in capacitive sensors. A simple displacement sensor can be easily built using a cylindrical capacitor if the inner conductor can be moved in and out of the outer conductor (Fig. 3.9). According to Eq. (3.2), the capacitance of such a sensor is in a linear relationship with the displacement *l*.

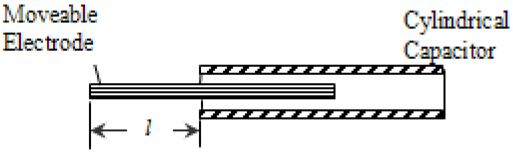


Fig. 3.9. A Capacitive Displacement Sensor.

Coaxial capacitors are commonly used for fluid level measurement. There are two designs: one for fluids with low dielectric constants (or high conductivity, see Fig. 3.10a), and another for fluids with high dielectric constants (or low conductivity, see Fig. 3.10b). In Design (a), the surface of the metal electrode is coated with a thin isolating layer (e.g., Teflon or Kynar) to prevent an electric short circuit through the liquid. The insulated probe acts as one plate of the capacitor and the conductive liquid acts as the other, and it is electrically connected to the ground. The insulating or dielectric medium in this case is the probe's sheath. In Design (b), a bare rod and the metallic vessel wall form the electrodes of a capacitor; the dielectric medium is the liquid. The vessel wall (or reference probe) is grounded in this case. Usually, a potentiometer is built in so that liquids with different densities and different dielectric constants can be measured. A bridge circuit measures the capacitance and provides continuous liquid level monitoring.

(a) (b)

Fig. 3.10. Capacitive Liquid Level Sensors.

The cross section of a capacitive touch transducer is shown in Fig. 3.11. This sensor uses a coaxial capacitor design and a high dielectric polymer (e.g., polyvinylidene fluoride) to maximize the change in capacitance as force is applied. The movement of one set of the capacitor's plates is used to resolve the displacement and hence applied force, which causes a capacitance change. From an application viewpoint, the coaxial design is better than a flat plate design as it will give a greater capacitance increase for an applied force.

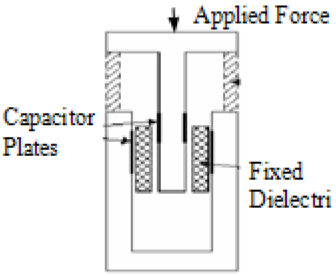


Fig. 3.11. Schematic of a Coaxial Capacitor Touch Sensor.

Euro Gulf Group Company has developed a*n Oil Analyzer* (EASZ-1), which uses the capacitance principle to measure moisture content in oil (see Fig. 3.12a and b). The cylindrical sensor and outer barrel are fixed in size and distance from each other and form the electrodes of a coaxial capacitor. The oil sample flows between the "plates" as a dielectric fluid, changing the capacitance of the assembly proportionally with the change in dielectric constant of the fluid. The measured capacitance is then converted to a water content output signal by the microprocessor and associated components to deliver stable and accurate readings. There is also a built-in temperature sensor for temperature compensation.

(a) (b)

Fig. 3.12. EASZ-1 Analyzer (a) and its Typical Installation on a Hydraulic Line (b).

Spherical Capacitor-Based Sensors

Spherical capacitive sensors are not as popular as the parallel or cylindrical configurations. This is largely due to the spherical design's complexity and higher manufacturing cost. However, the spherical geometry does provide several unique features, neither flat-plate nor coaxial capacitors have, such as higher capacitance within a limited or compact space, a shape that is more readily adaptable to measure irregular surfaces, spherical equipotentials, and wider bandwidth.

A spherical capacitor provides the ideal shape for generating a nonlinear electric field gradient between its centre electrode and its inner surface. This unique feature was utilized by scientists at NASA (National Aeronautics & Space Administration) to create the *geophysical fluid flow cell* (GFFC, see Fig. 3.13).

Fig. 3.13. The NASA GFFC Device.

This cell uses spherical capacitors to simulate gravitational field conditions for studying the behaviour of fluids. By applying an electric field across a spherical capacitor filled with a dielectric liquid, a body force analogous to gravity is generated around the fluid. The force acts as a buoyant force with magnitude proportional to the local temperature of the fluid and in a radial direction perpendicular to the spherical surface. In this manner, cooler fluid sinks toward the surface of the inner sphere, while warmer fluid rises toward the outer sphere. Researchers at *University of Shanghai for Science and Technology* in China utilized the unique shape of the spherical capacitor to design a probe for measuring the thickness of coatings on metals [13]. This spherical capacitive probe is more accurate in measuring the thickness of non-conducting coatings on metals than the common planar probes. Also, because it is a capacitive sensor, it is not subject to the materials limitations of the magnetic induction method and the eddy current method, both having the disadvantage of being strongly influenced by the electroconductivity and magnetic conductivity of the substrate.

Capacitive Sensor Arrays

Capacitive sensors can also be arranged in arrays to perform more sophisticated tasks. Fig. 3.14 shows a spherically folded capacitive pressure sensor array (1mm thickness) for 3D measurements of pressure distribution in artificial joints [14]. The sensor array consists of 192 sensor elements which are arranged in a 16x16 matrix (Fig. 3.14a), then folded spherically (Fig. 3.14b) and placed in a cavity (60mm diameter, Fig. 3.14c), followed by a ball joint (50mm diameter, Fig. 3.14d). This unique sensor can be used to measure pressure distributions along curved surfaces such as those in ball joints.

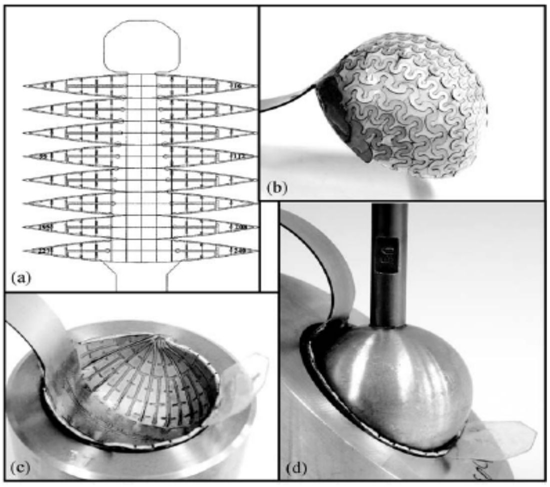


Fig. 3.14. (a) Unfolded Sensor Array; (b) Spherically Folded Sensor Array; (c) Sensor Array Placed in a Cavity; (d) Sensor Array between Ball and Cavity.

In Fig. 3.15, the *iGuard Security System* [15] and *Fingerprint Cards'* [16] sensor contains tens of thousands of small capacitive plates (functioning as pixels), each with their own electrical circuit embedded in the chip. When a finger is placed on the sensor, extremely weak electrical charges are created. Using these charges the sensor measures the capacitance pattern across the surface. Where there is a ridge or valley, the distance varies, as does the capacitance; building a pattern of the finger's "print". The measured values are digitized by the sensor then sent to the microprocessor.

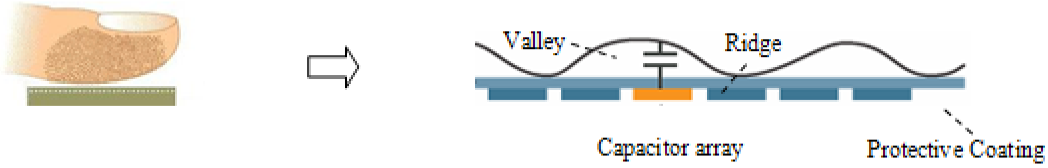


Fig. 3.15. A Capacitive Fingerprint Sensor.

This capacitance sensing technique is an effective method for acquiring fingerprints. To achieve enough sensitivity, the protective coating must be very thin (a few microns), since an electrical field is measured and the distance between the skin and the pixels is very small. A significant drawback to this design is its vulnerability to strong external electrical fields, the most troublesome being ESD (Electro-Static Discharge).

4. Summary

Resistive and capacitive sensors are the most broadly used sensors. They can measure or detect a broad range of physical phenomena and parameters, such as position, displacement, acceleration, pressure, force, humidity, temperature, radiation, light, current, flowrate, chemical particles/gases, bioactivity, and more. Electrical resistance is the easiest electrical property to measure and can provide a high degree of precision over a wide range. The physical principles of resistive sensors are governed by several important laws and phenomena such as *Ohm's Law* and *Wiedemann-Franz Law*;

Photoconductive-, *Piezoresistive-*, and *Thermoresistive Effects*, which relate electrical resistance values to the magnitude of the physical or chemical parameters. The operating principles of capacitive sensors are based on the properties of a capacitor: *capacitance variation is a function of changes in dielectric constant, materials, electrode conductivity, and geometric parameters*. Each capacitive sensor is designed to measure one or more of these parameters. All capacitive sensors fall into one of the three basic capacitor configurations: flat-plate, coaxial, or spherical, depending on their intended use and function. Several typical sensor designs and applications in each configuration, as well as sensor arrays, are described in the paper.

References

[1]. W. Du., S. Yelich, Resistive Sensors: Principles, Design, and Applications, Proceedings of the *2nd International Conference on Sensing Technology,* Nov. 26-28, 2007, Palmerston North, New Zealand, pp. 326-331.

[2]. W. Du., S. Yelich, Capacitive Sensors: Principles, Design, and Applications, Proceedings of the *2nd International Conference on Sensing Technology,* Nov. 26-28, 2007, Palmerston North, New Zealand, pp. 332-337.

[3]. Introduction to Capacitance Gages, *ADE Technologies,* p. 6.

[4]. H. P. Schwan, The Bioimpedance Field: Some Historical Observations, *Proceedings of 9th ICEBI*, Heidelberg, Germany, 1995.

[5]. J. Fraden, Handbook of Modern Sensors: Physics, Designs, and Applications, *Springer-Verlag*, 2003.

[6]. E. Källvesten, P. Melvas, J. Melin, T. Frisk, G. Stemme, Ultra-miniaturized Pressure Sensors for Intravascular Blood Pressure Measurements, *KTH Royal Inst. of Tech., Sweden*.

[7]. T. Montgomery, Industrial Temperature Primer, *Wilkerson Instrument Co.* , 2007*,* p. 11.

[8]. L. V. King, On the Convention of Heat from Small Cylinders in a Stream of Fluid, *Phil. Trans. Roy. Soc.*, A214, 1914, p. 373.

[9]. G. Man, A. Navabi, T. Raymond, B. Stoeber, K. Walus, Polymer-based Chemical Sensors for Clandestine Lab Detection, *CMC Workshop on MEMS & Microfluidics*, Montreal, Canada, 2007.

[10].T. J. Plum, V. Saxena, and J.R. Jessing, Design of a MEMS Capacitive Chemical Sensor Based on Polymer Swelling, *IEEE WMED 2006*.

[11].J. Engel, J. Chen, N. Chen, S. Pandya, and C. Liu, Multi-Walled Carbon Nanotube Filled Conductive Elastomers: Materials & Application to Micro Transducers, *19th IEEE International Conference on Micro Electro Mechanical Systems*, Istanbul, Turkey, Jan. 22-26, 2006, pp. 246-249.

[12]. C. Guiducci, C. Stagni, A. Fischetti, U. Mastro-matter, Microelectrodes on a Silicon Chip for Label-free Capacitive DNA Sensing, *Sensor Journal*, Vol. 6, No. 5, 2006, pp. 1084-1093.

[13].R. Zhang, S. Dai, and P Mu, A Spherical Capacitive Probe for Measuring the Thickness of Coatings on Metals, *Measurement Science Technology*, 8, 1997, pp. 1028–1033. (Printed in the UK).

[14].O. Muller, W. J. Parak, M. G. Wiedemann, and F. Martini, Three-Dimensional Measurements of the Pressure Distribution in Artificial Joints with A Capacitive Sensor Array, *Journal of Biomechanics*, 37, 2004, 1623–1625.

[15].Solid-state, Silicon-based Capacitive Fingerprint Sensor, Retrieved on Jan. 20, 2008 at www.iguardsystem.com.

[16].Fingerprint Sensing Techniques," retrieved on Sept. 20, 2007 at: http://perso.orange.fr/fingerchip/biometrics/types/fingerprint_sensors_physics.htm

Guide for Contributors

Aims and Scope

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

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 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf


SENSORS & TRANSDUCERS
1/08
Sensor Instrumentation, DAQ and Virtual Instruments
International Frequency Sensor Association Publishing
IFSA