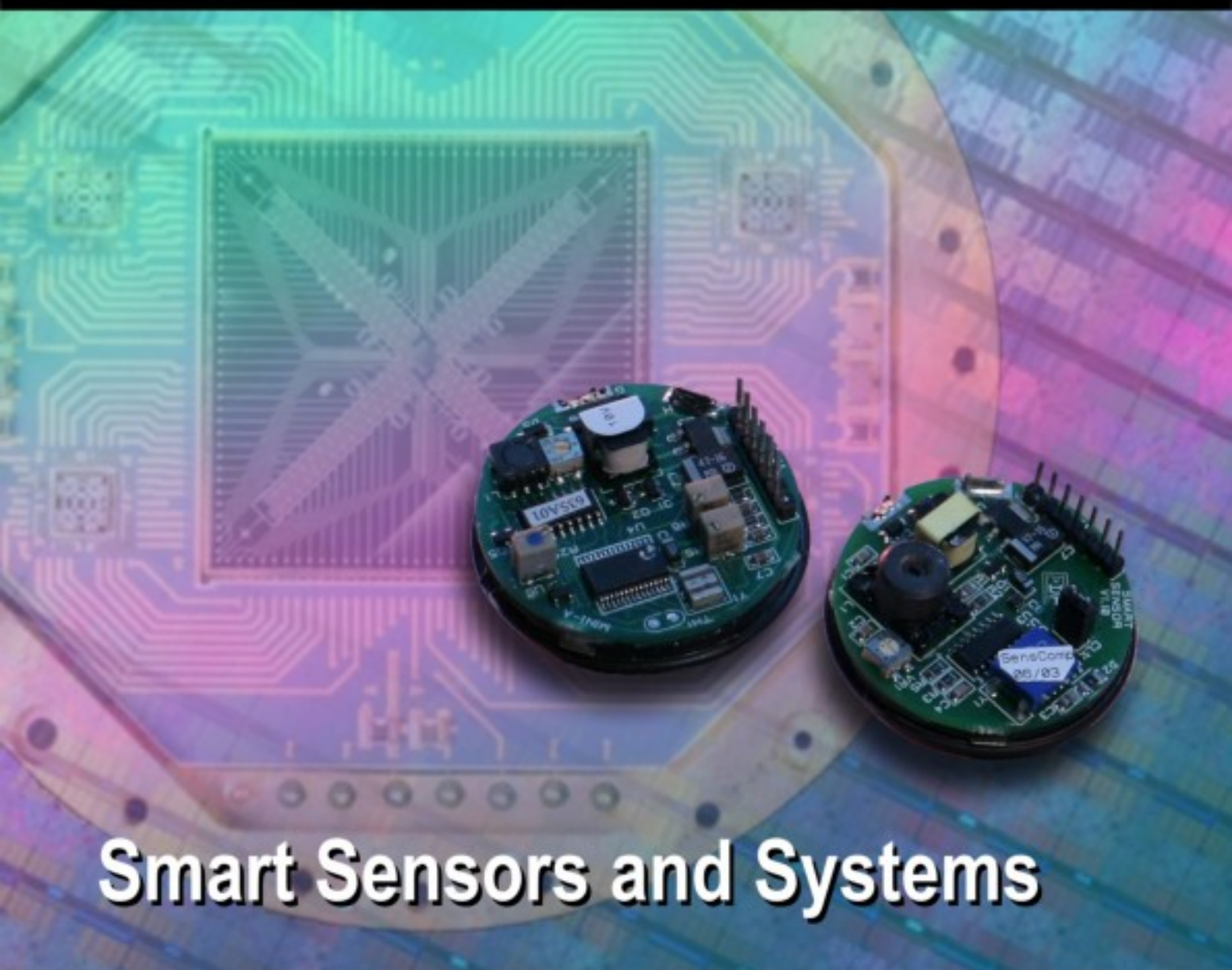


ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 102
3/09



Smart Sensors and Systems

International Frequency Sensor Association Publishing



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

Editors for Western Europe

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

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America

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

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific

Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, 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, Vyantas, 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
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
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 Jian, Ning, Jiangsu University, China
Djordjevic, Alexander, City University of Hong Kong, Hong Kong

Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Intersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, 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
Grael, 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
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South
Sandacci, Serghei, Sensor Technology Ltd., UK

- 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, Saisune**, 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
- Mulla, Imtiaz Sirajuddin**, National Chemical Laboratory, Pune, India
- Neelamegam, Periasamy**, Sastra Deemed University, India
- Neshkova, Milka**, Bulgarian Academy of Sciences, Bulgaria
- Oberhammer, Joachim**, Royal Institute of Technology, Sweden
- Ould Lahoucine, Cherif**, University of Guelma, Algeria
- Pamidighanta, Sayanu**, Bharat Electronics Limited (BEL), India
- Pan, Jisheng**, Institute of Materials Research & Engineering, Singapore
- Park, Joon-Shik**, Korea Electronics Technology Institute, Korea South
- Penza, Michele**, ENEA C.R., Italy
- Pereira, Jose Miguel**, Instituto Politecnico de Setebal, Portugal
- Petsev, Dimiter**, University of New Mexico, USA
- Pogacnik, Lea**, University of Ljubljana, Slovenia
- Post, Michael**, National Research Council, Canada
- Prance, Robert**, University of Sussex, UK
- Prasad, Ambika**, Gulbarga University, India
- Prateepasen, Asa**, Kingmoungut's University of Technology, Thailand
- Pullini, Daniele**, Centro Ricerche FIAT, Italy
- Pumera, Martin**, National Institute for Materials Science, Japan
- Radhakrishnan, S.**, National Chemical Laboratory, Pune, India
- Rajanna, K.**, Indian Institute of Science, India
- Ramadan, Qasem**, Institute of Microelectronics, Singapore
- Rao, Basuthkar**, Tata Inst. of Fundamental Research, India
- Raof, Kosai**, Joseph Fourier University of Grenoble, France
- Reig, Candid**, University of Valencia, Spain
- Restivo, Maria Teresa**, University of Porto, Portugal
- Robert, Michel**, University Henri Poincare, France
- Rezazadeh, Ghader**, Urmia University, Iran
- Royo, Santiago**, Universitat Politècnica de Catalunya, Spain
- Rodriguez, Angel**, Universidad Politécnica de Cataluña, Spain
- Rothberg, Steve**, Loughborough University, UK
- Sadana, Ajit**, University of Mississippi, USA
- Sadeghian Marnani, Hamed**, TU Delft, The Netherlands
- Sapozhnikova, Ksenia**, D.I.Mendeleyev Institute for Metrology, Russia
- Saxena, Vibha**, Bhabha Atomic Research Centre, Mumbai, India
- Schneider, John K.**, Ultra-Scan Corporation, USA
- Seif, Selemeni**, Alabama A & M University, USA
- Seifter, Achim**, Los Alamos National Laboratory, USA
- Sengupta, Deepak**, Advance Bio-Photonics, India
- Shankar, B. Baliga**, General Monitors Transnational, USA
- 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
- Soleymannpour, Ahmad**, Damghan Basic Science University, Iran
- Somani, Prakash R.**, Centre for Materials for Electronics Technol., India
- Srinivas, Talabattula**, Indian Institute of Science, Bangalore, India
- Srivastava, Arvind K.**, Northwestern University, USA
- Stefan-van Staden, Raluca-Ioana**, University of Pretoria, South Africa
- 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
- Vazquez, Carmen**, Carlos III University in Madrid, Spain
- Vieira, Manuela**, Instituto Superior de Engenharia de Lisboa, Portugal
- Vigna, Benedetto**, STMicroelectronics, Italy
- Vrba, Radimir**, Brno University of Technology, Czech Republic
- Wandelt, Barbara**, Technical University of Lodz, Poland
- Wang, Jiangping**, Xi'an Shiyou University, China
- Wang, Kedong**, Beihang University, China
- Wang, Liang**, Advanced Micro Devices, USA
- Wang, Mi**, University of Leeds, UK
- Wang, Shinn-Fwu**, Ching Yun University, Taiwan
- Wang, Wei-Chih**, University of Washington, USA
- Wang, Wensheng**, University of Pennsylvania, USA
- Watson, Steven**, Center for NanoSpace Technologies Inc., USA
- Weiping, Yan**, Dalian University of Technology, China
- Wells, Stephen**, Southern Company Services, USA
- Wolkenberg, Andrzej**, Institute of Electron Technology, Poland
- Woods, R. Clive**, Louisiana State University, USA
- Wu, DerHo**, National Pingtung 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, Netherlands
- Yong Zhao**, Northeastern University, China
- Yu, Haihu**, Wuhan University of Technology, China
- Yuan, Yong**, Massey University, New Zealand
- Yufra 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, Quintao**, 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

Contents

Volume 102
Issue 3
March 2009

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Smart Sensor Systems: Book Review	I
Design of a Smart and High Precision Industrial Temperature Measurement and Monitoring System Using K-type Thermocouple and SPI-compatible Temperature Sensor <i>Utpal Sarma, Digbijoy Chakraborty, P. K. Boruah</i>	1
IEEE 1451.0-2007 Compatible Smart Sensor Readout with Error Compensation Using FPGA <i>J. Kamala and B. Umamaheswari</i>	10
Predicting the Deflections of Micromachined Electrostatic Actuators Using Artificial Neural Network (ANN) <i>Hing Wah Lee, Mohd. Ismahadi Syono and Ishak Hj. Abd. Azid</i>	22
Conception and Development of a Portable Electronic Nose System for Classification of Raw Milk Using Principal Component Analysis Approach <i>Hing Wah Lee, Mohd. Ismahadi Syono and Ishak Hj. Abd. Azid</i>	33
Viscosity Measurement Using Microcontroller to Study the Thermal Degradation of Edible Oil <i>Neelameagam Periyasamy, Rubalya Valantina Sathianathan and Murugananthan Krishnamoorthy</i>	45
Problems of Terminology in the Field of Measuring Instruments with Elements of Artificial Intelligence <i>Roald Taymanov, Ksenia Sapozhnikova</i>	51
Microcontroller Based Closed Loop PMDC Motor Position Control System <i>Subrata Chattopadhyay, Utpal Chakraborty, Arindam Bhakta and Sagarika Pal</i>	62
Discrete Time Sliding Mode Control Using Fast Output Sampling Feedback for Piezoelectric Actuated Structures <i>L. R. Karl Marx, M. Umapathy, A. Girija, D. Ezhilarasi</i>	71
A Particle Swarm Optimization of Natural Ventilation Parameters in a Greenhouse with Continuous Roof Vents <i>Abdelhafid Hasni, Belkacem Draoui, Thierry Boulard, Rachid Taibi and Brahim Dennai</i>	84
Experimental and Computational Study of Two-phase (Air–Palm Oil) Flow through Pipe and Control Valve in Series <i>Arivazhagan M., Pugalenth, Krishna Karthik K., Rani Hemamalini, Sundaram S.</i>	94
The Effect on Pressure Drop across Control Valve for Two Phase Flow (Air-Water) <i>Arivazhagan M, Krishna Karthik K, Sundaram S</i>	105
RBIC-Lite – a Family of Signal Conditioning ICs of ZMD <i>Krauss Gudrun, Krauss Mathias</i>	115

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

International Frequency Sensor Association (IFSA).

Conception and Development of a Portable Electronic Nose System for Classification of Raw Milk Using Principal Component Analysis Approach

¹Aziz AMARI, ²Nezha EL BARI, and ^{1*}Benachir BOUCHIKHI

¹Sensor Electronic & Instrumentation Group, Faculty of Sciences, Physics Department,
Moulay Ismaïl University, B.P. 11201, Zitoune, Meknes, Morocco

²Biotechnology Agroalimentary and Biomedical Analysis Group, Faculty of Sciences,
Biology Department, Moulay Ismaïl University, B.P. 11201, Zitoune, Meknes, Morocco
E-mail: ^{*}benachir.bouchikhi@gmail.com, amariaziz2004@yahoo.fr, n_elbari@hotmail.com

Received: 5 February 2009 /Accepted: 24 March 2009 /Published: 31 March 2009

Abstract: The analysis of the aroma of milk is an especially complex problem due to the heterogeneous nature of milk. In the present study, a portable electronic nose has been fabricated and characterized using an oxide semiconductor gas sensor array. The portable electronic nose system, based on Taguchi Gas Sensors (TGS), consists of a microcontroller PIC16F877 as CPU, an LCD for displaying gas conductance and a LabVIEW® PC interface for data acquisition, etc. To check its separation capability a pattern recognition method namely Principal Component Analysis (PCA) has been performed. The PCA method permits a good classification between three types of raw milks from different dairy farms. On the other hand, the data coming from the response of the sensors have been elaborated by PCA and Support Vectors Machines (SVMs) in order to obtain a classification of the data clusters related to different milk ageing days and so track the dynamic evolution of milk rancidity. It was found that the portable electronic nose system together with a pattern recognition technique, PCA or SVMs is able to show a characteristic development of the milk quality, when it is stored at 4 °C, dependent on storage time. The last section draws the evaluation of the hygienic quality of raw milk, the following microbiological counts were determined: yeast and mould counts, total coliform count and total aerobic mesophilic flora count. *Copyright © 2009 IFSA.*

Keywords: Electronic nose, Principal component analysis, Support vector machines, Milk quality, Raw cows' milk

1. Introduction

One of the most important technological steps in the production of dairy products is the quality control of starting milk. The chemical analysis of flavours in dairy products is complicated by the heterogeneous nature of milk. The control of milk quality and freshness is of increasing interest for both the consumer and the beverages industries. The profile of the volatile components of milk and dairy products is performed today by gas chromatography-mass spectrometry (GC-MS) [1, 2] coupled with highly efficient systems of extraction, such as dynamic or static headspace. These Classical analytical techniques are, however, time-consuming, expensive, and laborious, which can hardly be done on-site or on-line [3].

It has been shown that a new system, named “electronic nose” can be used as a powerful method to control the quality of food in some specific applications [4-10]. This innovative system consists of a multi-sensors array capable to monitor the interaction with specific molecules as a consequence of adsorption/desorption processes occurring on the surface of the sensors. A suitable electronics and software allow to perform quantitative and qualitative analysis of a mixture of gases using headspace analysis method. Static headspace analysis involves sampling air, equilibrated above a milk sample and injecting into a gas analytical instrument (into sensor’s chamber of the electronic nose system) for classification and identification. Dynamic headspace analysis requires a carrier gas in the sampling of volatiles above a milk sample.

In the work reported here, a portable electronic nose system has been fabricated and characterized using an oxide semiconductor gas sensor array. The employed sensor array consists of six different available Taguchi gas sensors (TGS). The data coming from the response of the sensors have been elaborated by principal component analysis (PCA) and support vectors machines (SVMs). The aim of this work was to explore the capabilities of a simple electronic nose device to discriminate among raw milks of three different dairy farms. And also to perform a characterization of one raw milk in different ageing days, simple PCA algorithm was used to process the data and to follow the evolution of the data clusters related to different ageing days. SVMs have been used for the recognition of different storage days of raw milk.

2. Experimental

2.1. Milk Samples

The raw cows’ milks used in this study were collected from three different dairy farms around the city of Meknes (Morocco) in the cool season (April 2007). Fresh samples were, immediately after receiving, placed in plastic bottles (1.5 L/bottle) and introduced in a refrigerator kept at a constant temperature of 4 °C to be analyzed at 1, 2, 3, and 4 days of storage.

2.2. Description of the Developed Portable Electronic Nose

The electronic nose used has been home-fabricated and home-developed for milk aroma purposes. The developed system is mainly composed of three parts: E-nose case, sampling vessel, and laptop PC equipped with a software acquisition of data. The E-nose case includes sensors cell, sensors array and a programmable microcontroller.

2.2.1. Sensors Array

The sensors of the electronic nose are assembled in an array. The array is normally a small electronic unit that integrates the different sensors into a practical circuit card that is easy to insert into the electronic nose instrument. The resistive gas sensors we used are of MOS (Metal-Oxide Semiconductor) such as tin dioxide. The sensors array comprised six TGS 8XX (with XX= 15, 21, 22, 24, 25 and 42), a relative humidity sensor (HIH4000-01) and a temperature sensor (LM335Z) from National Semiconductor are used to monitor the conditions of the experiment [9, 10]. The inside arrangement of components of the sensing module is shown in Fig. 1.



Fig. 1. Photo of TGS sensors array.

2.2.2. Sampling Vessel and Measurement Rig

The sampling system consists of a dynamic headspace sampling. For the measurement a volume of 100 mL of milk in a 200 mL vial kept at the temperature of 35 °C, was stripped by means of the 1000 sccm nitrogen flow for 10 mn. In this way, the volatile compounds were directly transferred by the carrier gas into the sensors chamber. The vial had two small holes in their covers to allow the headspace to be analyzed with the electronic nose equipment. Each time that a new set of milk was analyzed, new glass vials were used.

2.2.3. Microcontroller Circuit

The developed portable electronic nose system consists of a microcontroller PIC16F877 as CPU, an LCD. Fig. 2 gives the electronics circuit for the microcontroller used. For each measurement the response of sensor arrays was converted with a 10-bits ADC implemented in the microcontroller. An LCD is used for displaying gas conductance, relative humidity and temperature.

2.2.4. Data Acquisition

Data acquisition and device control are accomplished using a PIC16F877 microcontroller with a software programme running on the laptop PC. The Laptop communicates via RS232 with the microcontroller electronics. Fig. 3 depicts a schematic view of the portable electronic nose measurements. There is a software programme running on the laptop, which controls the electronics and acquires data from the sensor operations (Fig. 4). This software was developed using LabVIEW© software (National Instruments Inc.).

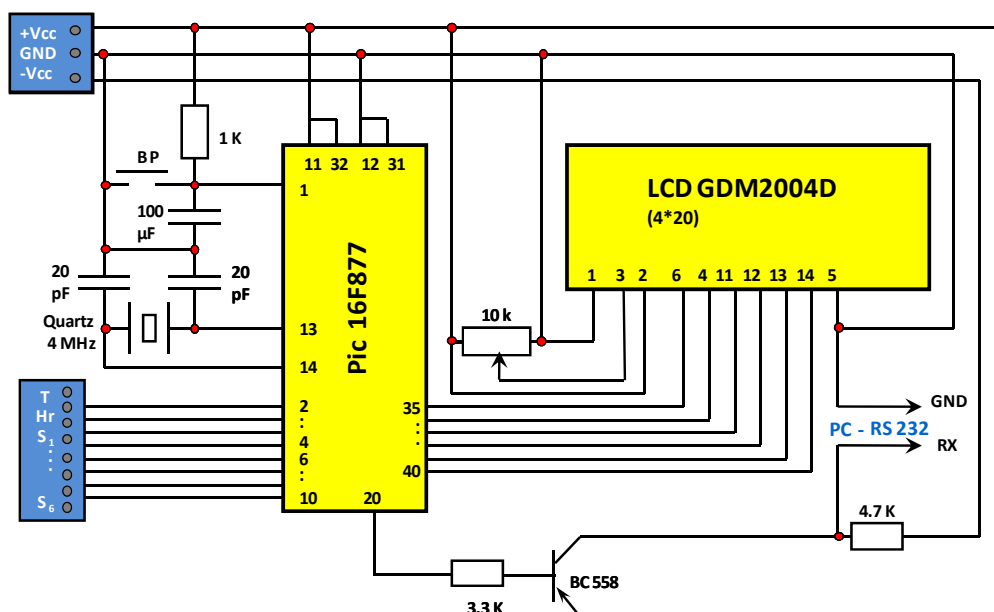


Fig. 2. Circuitual schematics of the microcontroller-LCD.

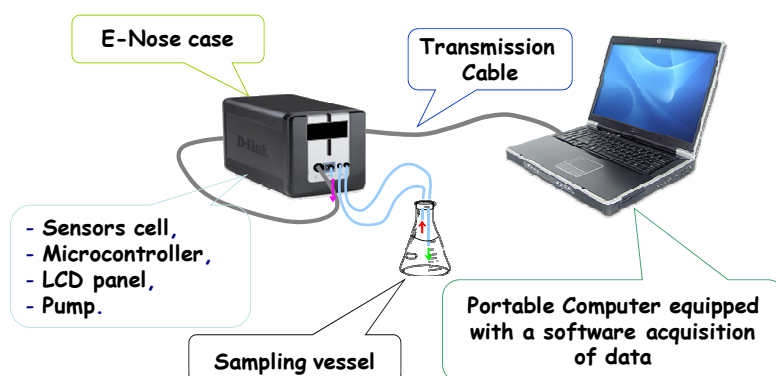


Fig. 3. Schematic representation of the portable electronic nose system.

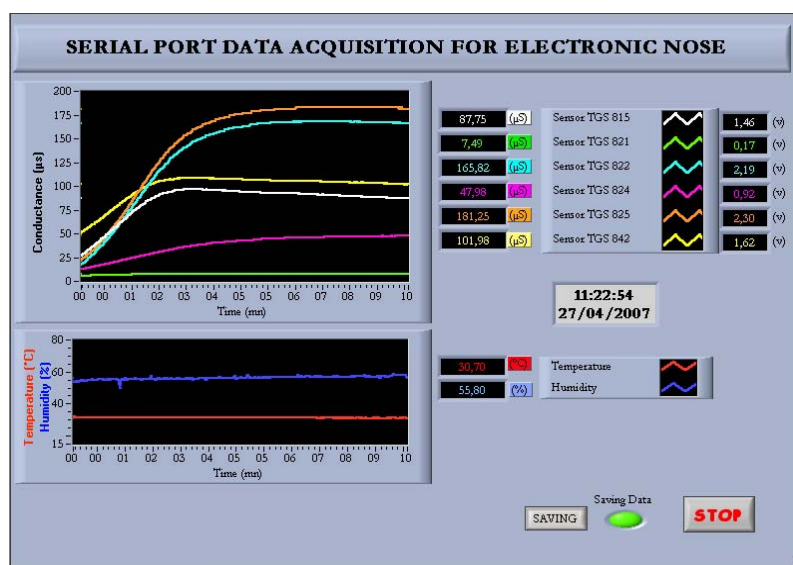


Fig. 4. Typical LabVIEW© PC interface for the electronic nose system.

2.2.5. Data Analysis

The use of PCA to assess clustering within the datasets is discussed below. The objective of using these methods was to establish classes according to the states of rancidity of milk. PCA is a powerful, linear, and ‘unsupervised’ pattern recognition technique that has been shown to be effective for discriminating between the responses of an electronic nose to simple and complex odours [11]. PCA decomposes the primary data matrix by projecting the multidimensional data onto a new coordinate base formed by the orthogonal directions with data maximum variance. The eigenvectors of the data matrix are called Principal Components (PC) and they are uncorrelated among them. The principal components are ordered so that the first one displays the greatest amount of variance, followed by the next greatest and so on.

Support vector machines approach was also used, as a supervised learning technique, for discriminate analysis. SVMs have demonstrated to be a powerful learning method [12] and its use in the electronic nose field is getting more importance [13]. SVMs were originally designed for binary classification. Currently there are two types of approaches for multi-class SVM. One is by constructing and combining several binary classifiers “one-against-one or one-against-all methods”, while the other is by directly considering all data in one optimization formulation [14]. The direct approach consists to construct a classifier recognizing the set of the classes: the determination of the hyper plane between these different classes permits to choose a class among the k when a new input is presented.

In our case, we have applied the one-against-all strategy to recognize the milk storage day; the “leave-one-out” validation procedure has been adopted for all the SVMs analysis. All the evaluations have been performed in Matlab 5.2.

3. Results and Discussion

3.1. Electronic Nose Responses and Signal Analysis

Fig. 5 shows the evolution of the signals generated by the 822 TGS sensor during the measurement of raw milk number 2 (dairy farm number 2) for all storage days. We show the same behaviour for all the other sensors. Each line represents the average signal variation of all milk samples measured in the same day respectively for each sensor of the array.

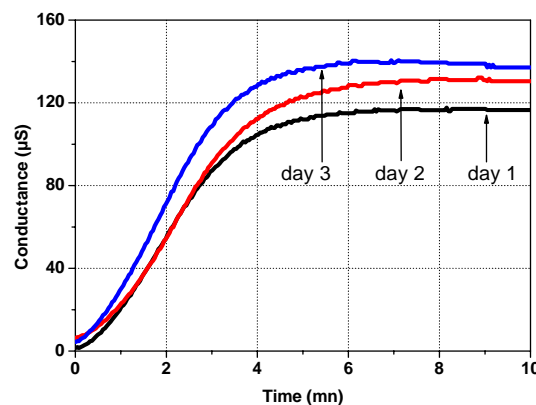


Fig. 5. Time conductance evolution of the TGS 822 sensor during storage days.

The evolution in sensor conductance can be directly attributed to the increasing number of storage days of milk (day 1, day 2 and day 3) and the effect of sensor drift can be ignored. This behaviour can be justified by an increase in the concentration of volatile gases given out by milks as a function of storage time. It can be shown that the sensor signals reach a plateau at the longest time. The measurement procedure was as follows: data acquisition started 30 sec before the transferring the volatile compounds by the carrier gas into the sensors chamber. This allowed for the baseline conductance of the sensors to be acquired. Acquisition ended after 10 mn and the sensor chamber was flushed with nitrogen air. The features extracted from the response of each sensor in the array are:

- G_0 : the initial conductance of a sensor calculated as the average value of its conductance during the first 30 second of a measurement.
- G_s : the steady-state conductance calculated as the average value of its conductance during the last 2 min of a measurement.

These two features were extracted from the response of each sensor. Since there were 6 sensors within the array, each measurement was described by 12 features.

3.2. Characteristic Parameter Evolution

Fig. 6 shows the evolution of maximum conductance change as a characteristic parameter. We notice that the 822 and 825 TGS sensors showed the highest responses of the sensors of all the samples. However, the response of the sensors changes with storage days. It is shown that this characteristic parameter increases with storage days.

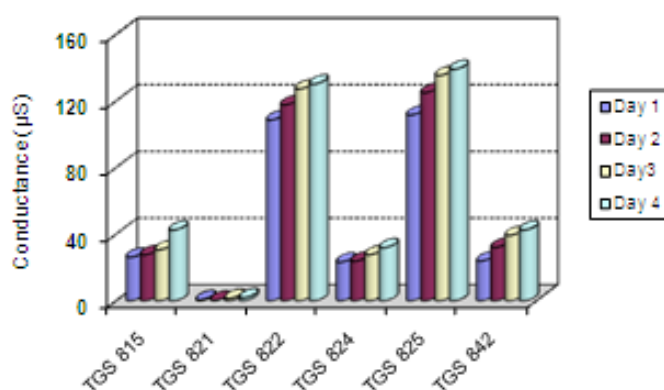


Fig. 6. Time variation of the maximum conductance change.

3.3. Classification of Raw Milks Using PCA Analysis

This experiment was devoted to study a dynamic evolution of the clusters related to different degrees of rancidity during a fixed time. In order to see whether the portable electronic nose was able to distinguish between different spoilage states, a PCA analysis was applied to the database [15, 16]. The analysis was done using all the responses that were obtained in the different measurements for milk number 2.

A mean centring pre-processing technique was applied to the response matrix. With PCA, the three first principal components allow us to clearly represent 99.31 % of the information in the database. Fig. 7 report, in three dimensional plot (PC1-PC2-PC3), the data coming from the measurements collected during a period of 4 days for raw milk no. 2. From the figure, it is quite evident as the 3D

PCA plot allows to well distinguishing the different days in which the milk has different rancidity values. It is reflecting how PCA analysis allows us to identify a preferential direction according to different of rancidity, giving an indication on the dynamic evolution of the system.

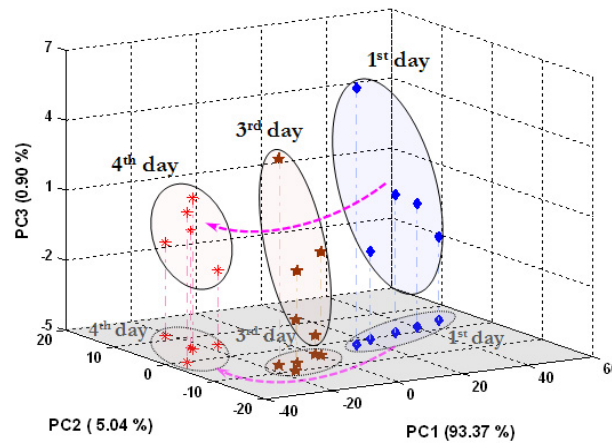


Fig. 7. PCA plot of raw milk no. 2 in different days.

3.4. Milk Ageing Analysis

In this study, we examine the second day of storage and we perform the same PCA analysis as described in Section 3.3. The first two components, PC1 and PC2, can be used to represent the 97.93 % of the data variance.

Fig. 8 shows the projections of the experimental results on a two-dimensional (2D) plane PC1-PC2. Samples can be grouped together in three different clusters. Each of these groups corresponds to 1st-2nd day, 3rd day and 4th day of storage, respectively. The 1st and 2nd day are not so distinctly separated, so they have similar properties and they are combined in one group. However, the 3rd and 4th days are sufficiently far from the other days so we can conclude that the DLC (date limit for consumption) of this raw milk, stored at 4 °C, is 2 days.

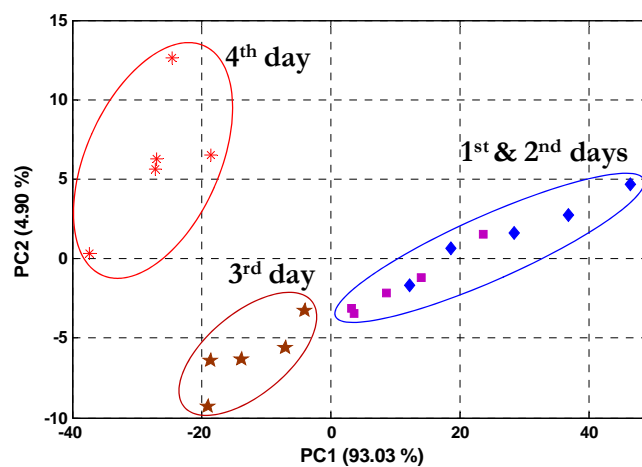


Fig. 8. PCA results in the PC1-PC2 plane for the analysis of milk at different storage days.

3.5. Evolution of Milk Quality with Time

The fact that samples appear ordered along the first principal component (PC1) according to the number of storage days is a significant result. The first principal component explains the main variance in the data (i.e., in the response of the sensors), and Fig. 8 shows that this variance is well correlated with the number of storage days. In other words, the sensor array employed seems appropriate to envisage an application where the main goal would be to predict the number of days of cold storage undergone by raw milk. A linear fit of the scores, whose equation is shown in Fig. 9, suggests that the value of the scores on the first PC could be used to predict the period of storage and, therefore, the decay in raw milk. These scores show a monotonic decrease during the period of storage.

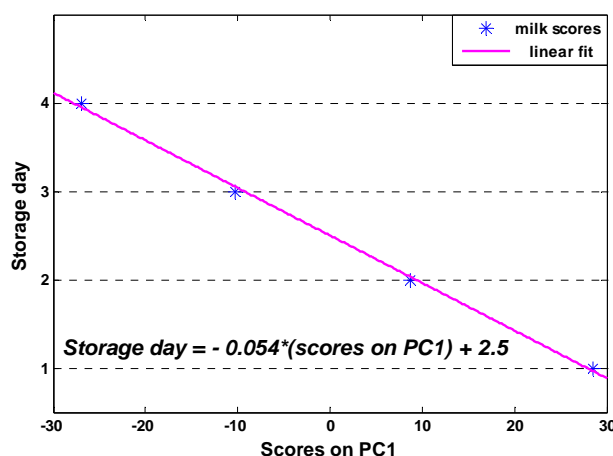


Fig. 9. Evolution of the scores on the first principal component with the period of storage and linear fitting.

3.6. Support Vector Machines Analysis

A SVMs one-against-all classification method was applied to develop the classifier model for our portable electronic nose. As in the PCA, 12 response features from the sensor array are used as inputs to the SVMs. Second-order of radial basis function (RBF) kernel are used to project the training data to a space that maximizes the margin hyper plane. The optimal regularization parameter of the SVM was set to $C = \text{Inf}$.

The performance of the SVM model is evaluated using a leave-one-out cross-validation method. In the first, autoscale pre-processing technique was applied to SVM dataset. Four binary classification models were performed (i.e., four groups). Then the output of SVM classifier was calculated with the largest voting.

Table 1. SVM classification results.

Predicted	Actual			
	Class 1	Class 2	Class 3	Class 4
Class 1	5	1	0	0
Class 2	0	4	0	0
Class 3	0	0	5	0
Class 4	0	0	0	5

The SVM reached a 95 % success rate in the recognition the four days of milk storage. Table 1 shows the confusion matrix of the SVM classifier. Columns indicate true values and rows, predicted categories. As it can be noticed in this table, one mistake is signaled: one measurement belonging to class 2 (i.e., second storage days) was misclassified as belonging to class 1 (i.e., first storage days). The SVM method gives a good generation.

3.7. Discrimination Among Three Types of Raw Milk Using PCA

In this case, PCA of the data was performed to determine the capability of the prototype system to discriminate between three types of raw milk from three different dairy farms. The dataset here was pre-processed using a standard mean centring approach. A good separation was obtained between the three clusters indicating three separate regions in the 3D space for the three types of raw milk. Fig. 10 shows the projections of the experimental results on a three-dimensional plot (3D).

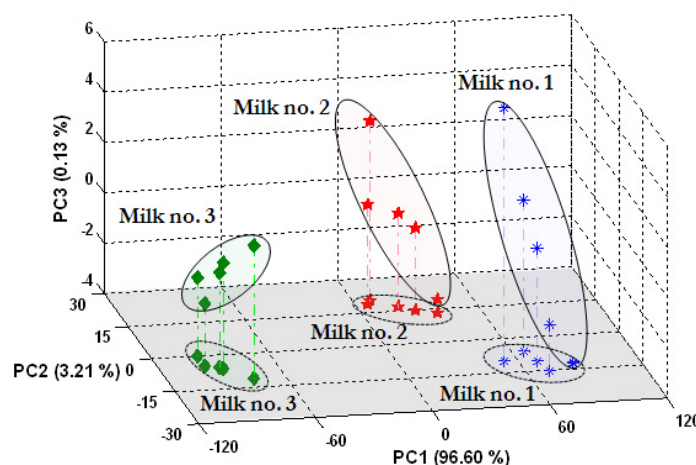


Fig. 10. PCA plot of different milks measured in the second day.

The three first principal components allow us to well represent 99.94 % of the information in the database. The data used in this study corresponding to the second storage day. So the 3D PCA plot allows us to well distinguish the three raw milks.

Winqvist et al. [17] report also a correct separation between milks from different sources, and thus, also having different quality properties with a voltammetric electronic tongue. This system has been further developed for industrial applications, and due to the ruggedness and simplicity, this concept has already proven valuable in many applications. Studies have shown that this electronic tongue could be used to monitor quality changes of milk [18], recognize different microbial species [19], and for supervision of rinses in a washing machine [20].

Fig. 11 shows the validation results obtained with the PCA model. This stringent test of the ability of the array and e-nose to identify samples was made by using the data from the milk experiment (dataset 1) as a training set and the second data (dataset 2) as the “unknown” for identification. The new samples appear correctly distributed according to their dairy farms. These results prove that the electronic nose system leads to reproducible results and that it can be used as a screening tool to differentiate between the three types of raw milk.

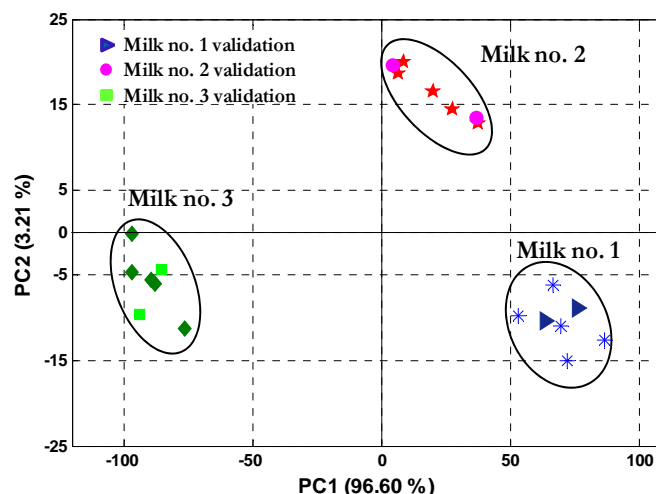


Fig. 11. Projection of the second set of measurements onto the PCA model built using the first set of measurements.

3.8. Microbiological Analysis

One of the most common tests is the viable cell count, the enumeration of viable microorganisms. It gives information on food quality, food spoilage and food safety. Even if they cannot be considered to be a “rapid method”, they will be used due to their importance for routine food testing. Originally, these methods were introduced to perform total viable counts: yeast and mould, total coliform and total aerobic mesophilic flora counts. The objectives of the present study were to determine the prevalence of potentially pathogenic microorganisms that indicate the hygienic and sanitary conditions of raw milk samples [21-23].

Yeast and mould counts: The yeast and mould count method proposed by Andrews (1992) was used to enumerate the yeast and moulds of the samples. An agar medium was employed, in which organisms other than yeast and mould were inhibited by using acidified media. After incubation at 25 °C for 3-5 days, the colonies were counted [24].

Total coliform count: The coliform count method proposed by Collins et al. (1995) was used. Make serial tenfold dilution and do plate counts with violet red bile lactone agar. Incubate at 30 °C for 24 hours. Counts only red colonies that are 0.5 mm in diameter or larger [24].

Total aerobic mesophilic flora count: The method of aerobic plate count proposed by Andrews (1992) was followed to determine the total colony count of the samples. A series of dilutions of the samples (10^{-1} and 10^{-2}) was made and 1 mL dilution mixed with aerobic plate agar in Petri dishes. After incubation at 37 °C for 48 hours, the colonies were counted [24].

The bacterial growth on the raw milk no. 2 stored at 4 °C is presented in Fig. 12. This figure shows the evolution of \log_{10} (cfu mL⁻¹) of total coliform, total aerobic mesophilic flora, and yeast and mould counts developed in raw milk as a function of the days of cold storage. The result of this work showed a big difference in microbial counts between the 2 first days and the 3rd - 4th days (Fig. 12). This is in agreement with the results found by using PCA analysis (section 3.4).

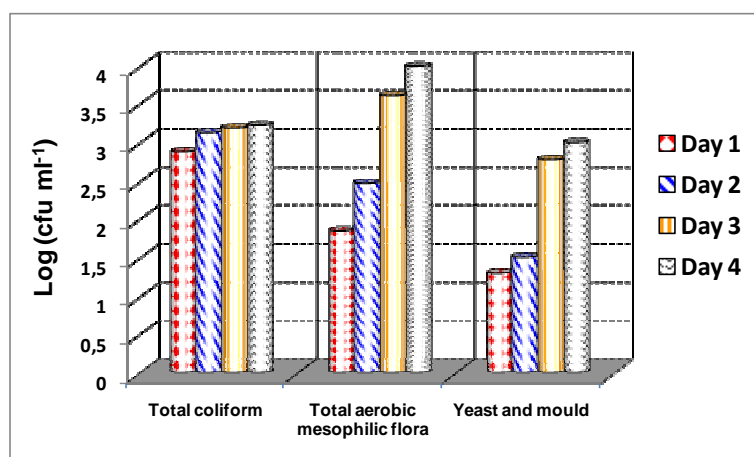


Fig. 12. Evolution of milk contamination (Log10 of total coliform, total aerobic mesophilic flora, and yeast/moulds counts) during storage days.

4. Conclusion

We have shown the feasibility of our prototype portable electronic nose based on an array of semiconductor gas sensors to detect off-odours from milk. It can be used to discriminate among milks from three different dairy farms. The sensor array coupled with features extraction and pattern recognition methods was found applicable to obtain selective discrimination of milk of different rancidity levels.

The proposed approach based on PCA application is of very good generalization with a success rate in discrimination of 99.94 %. The multi-class classifier model based on SVMs and the one-against-all, achieves very good accuracy in the classification. The results obtained with the developed approach and equipment are highly promising. PCA is able to show a characteristic development of the milk quality dependent on storage time; it gave a good estimation of the number of storage days. In conclusion, the system described may be of great use in the dairy industry. However the field of applications may further be widened and thus, it might become a challenging promise for food and beverage industry.

Acknowledgements

Microbiological analysis has been realized with the help of Asmaâ Khey and Ihssane Rifai under project of end of study for obtaining license diploma in General Biology.

References

- [1]. J. E. Friedrich, T. E. Acree, Gas chromatography olfactometry of dairy products, *Int. Dairy J.*, Vol. 8, 1998, pp. 235-241.
- [2]. R. Mariaca, J. O. Bosset, Instrumental analysis of volatile (flavours) compounds in milk and dairy products, *Lait*, Vol. 77, Issue 1, 1997, pp. 13-40.
- [3]. K. Brudzewski, S. Osowski, T. Markiewicz, Classification of milk by means of an electronic nose and SVM neural network, *Sensors and Actuators B*, Vol. 98, 2004, pp. 291-298.
- [4]. M. Benady, J. E. Simon, D. J. Charles, G. E. Miles, Determination melon ripeness by analyzing headspace gas emission, *Assoc. Soc. Agric. Eng.*, 1992, pp. 92-95.

- [5]. E. Moltoi, E. Selfa, J. Ferriz, E. Conesa, A. Gutierrez, An aroma sensor for assessing peach quality, *J. Agric. Eng. Res.*, Vol. 72, 1999, pp. 311-316.
- [6]. J. Brezmes, E. Llobet, X. Vilanova, G. Saiz, X. Correig, Fruit ripeness monitoring using an electronic nose, *Sensors and Actuators B*, Vol. 69, 2000, pp. 223-229.
- [7]. C. Di Natale, A. Macagnano, E. Martinelli, R. Paolesse, E. Proietti, A. D'Amico. The evaluation of quality of post-harvest orange and apples by means of an electronic nose. *Sensors and Actuators B*, Vol. 78, 2001, pp. 26-31.
- [8]. E. Llobet, E. L. Hines, J. W. Gardner, S. Franco, Non-destructive banana ripeness determination using a neural network-based electronics nose, *Sci. Technol.*, Vol. 6, 1999, pp. 538-548.
- [9]. A. Amari, N. El Barbri, E. Llobet, N. El Bari, X. Correig, B. Bouchikhi, Monitoring the freshness of Moroccan sardines with a neural-network based electronic nose, *Sensors*, Vol. 6, 2006, pp. 1209-1223.
- [10]. N. El Barbri, A. Amari, M. Vinaixa, B. Bouchikhi, X. Correig, E. Llobet, Building of a metal oxide gas sensor-based electronic nose to assess the freshness of sardines under cold storage, *Sensors and Actuators B*, Vol. 128, 2007, pp. 235-244.
- [11]. J. Brezmes, E. Llobet, X. Vilanova, J. Orts, G. Saiz, X. Correig, Correlation between electronic nose signals and fruit quality indicators on shelf-life measurements with pink lady apples, *Sensors and Actuators B*, Vol. 80, 2001, pp. 41-50.
- [12]. N. V. Vapnik, The Nature of Statistical Learning Theory, 1st Edition, *Springer-Verlag*, New York, 1998.
- [13]. S. Al-Khalifa, S. Maldonado, J. Gardner, Identification of CO and NO₂ using a thermally resistive microsensor and support vector machine, in *Proceedings of the Conference on' IEE Science Meas. and Tech.*, Vol. 150, 2003, Issue 6, pp. 11-14.
- [14]. C. -W. Hsu, C. -J. Lin. A comparison of methods for multi-class support vector machines. *IEEE Transactions on Neural Networks*, Vol. 13, 2002, pp. 415-425.
- [15]. T. Nakamoto, S. Sasaki, A. Fukuda, T. Moriizumi. Selection method of sensing membranes in odor-sensing system, *Sensors and Materials*, Vol. 4, 1992, pp. 111-119.
- [16]. M. O'Connell, G. Valdora, G. Peltzer, R. M. Negri, A practical approach for fish freshness determinations using a portable electronic nose, *Sensors and Actuators B*, Vol. 80, 2001, pp. 149-154.
- [17]. F. Winqvist, R. Bjorklund, C. Krantz-Rülcker, I. Lundström, K. Östergren, and T. Skoglund, An electronic tongue in the dairy industry, *Sensors and Actuators B*, Vol. 111-112, 2005, pp. 299-304.
- [18]. F. Winqvist, C. Krantz-Rülcker, P. Wide, I. Lundström, Monitoring of milk freshness by an electronic tongue based on voltammetry, *Meas. Sci. Technol.*, Vol. 9, 1998, pp. 1937-1946.
- [19]. C. Söderstrom, F. Winqvist, C. Krantz-Rülcker, Recognition of six microbial species with an electronic tongue, *Sens. Actuat. B*, Vol. 89, 2003, pp. 248-255.
- [20]. P. Ivarsson, M. Johansson, N. -E. Höjer, C. Krantz-Rülcker, F. Winqvist, I. Lundström, Supervision of rinses in a washing machine by a voltammetric electronic tongue, *Sens. Actuat. B*, Vol. 108, 2005, pp. 851-857.
- [21]. D. M. Barbano, Y. Ma, M. V. Santos, Influence of Raw Milk Quality on Fluid Milk Shelf Life, *J. Dairy Sci.*, Vol. 89 (E. Suppl.), 2006, E15-E19.
- [22]. N. Magana, A. Pavloub, I. Chrysanthakis, Milk-sense: a volatile sensing system recognises spoilage bacteria and yeasts in milk, *Sens. Actuat. B*, Vol. 72, 2001, pp. 28-34.
- [23]. F. Y. Chye, A. Aminah, A. Mohamed Khan, Bacteriological quality and safety of raw milk in Malaysia, *Food Microbiol.*, Vol. 21, 2004, pp. 535-541.
- [24]. F. Y. Chye, A. Aminah, A. Mohamed Khan, A Comparison on microbial conditions between traditional dairy products sold in Karak and same products produced by modern dairies, *Pak. J. Nutr.*, Vol. 4, 2005, pp. 345-348.

Guide for Contributors

Aims and Scope

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

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:

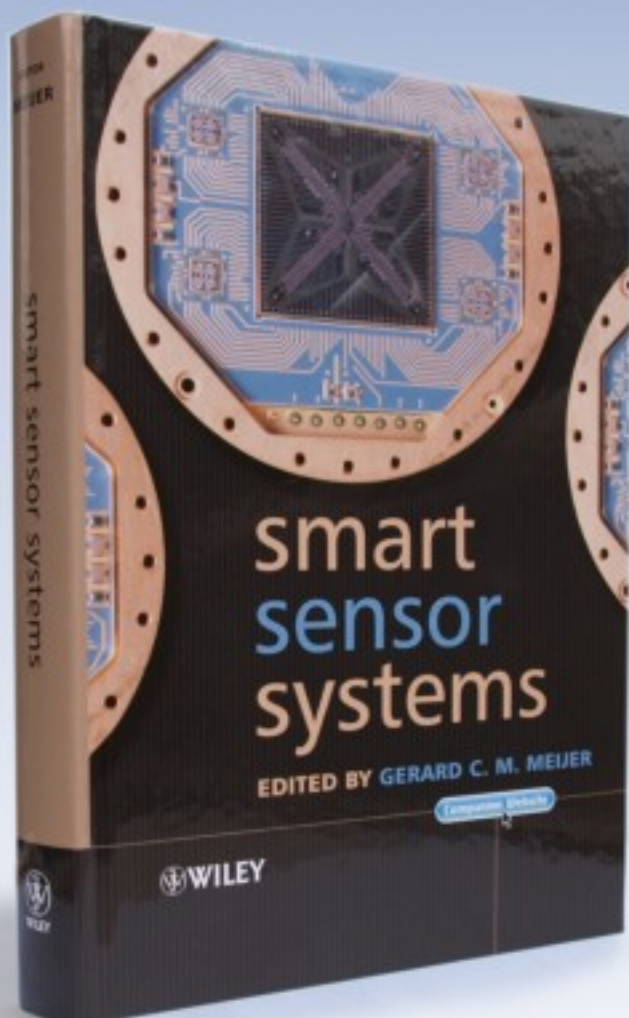
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors 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/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_2008.pdf



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



Order online:

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

www.sensorsportal.com