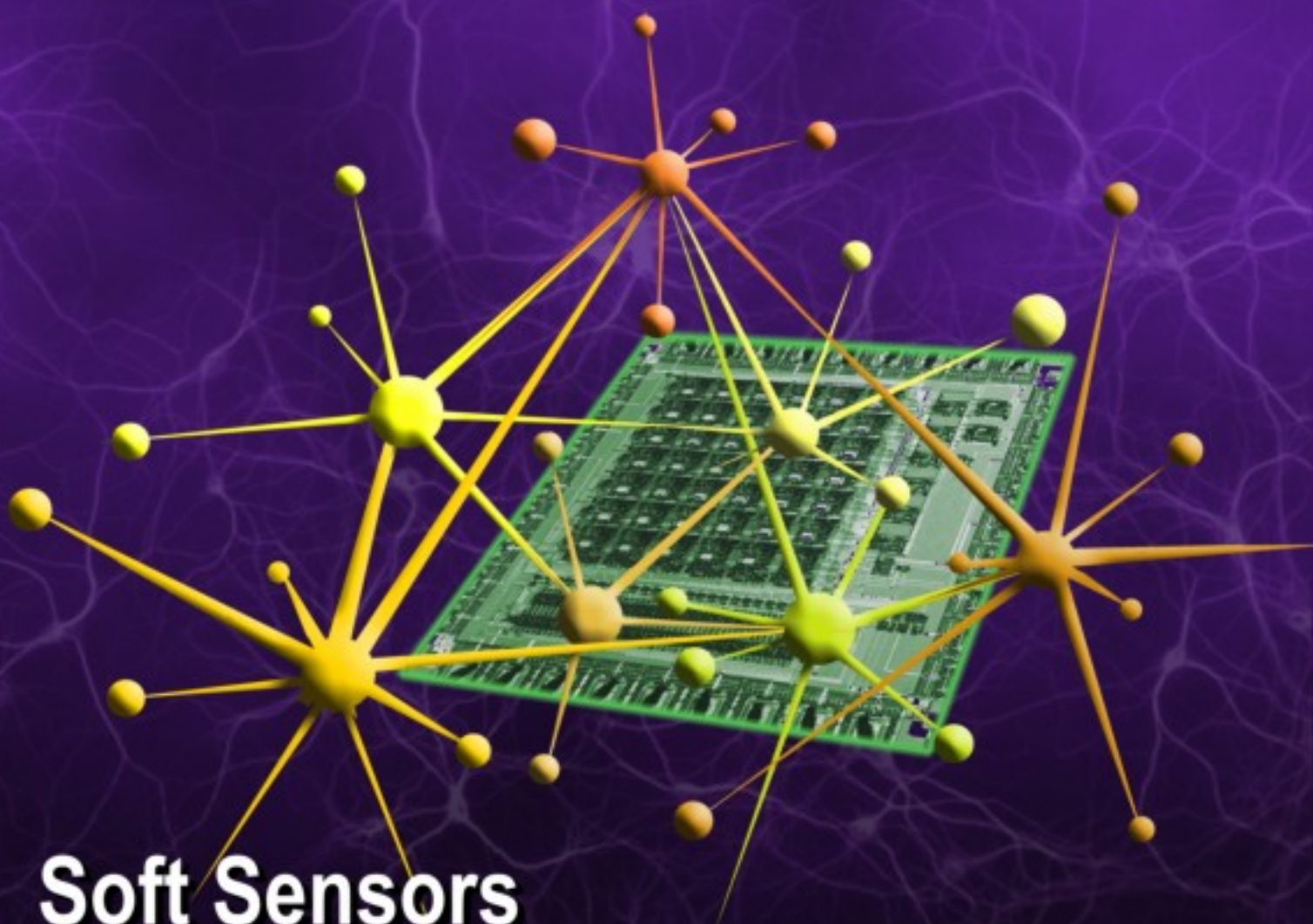


ISSN 1726-5749

# **S&Sensors & TRANSDUCERS** **10**<sup>vol. 84</sup>**/07**



## **Soft Sensors and Artificial Neural Networks**

International Frequency Sensor Association Publishing





# Sensors & Transducers

Volume 84  
Issue 10  
October 2007

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

ISSN 1726-5479

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

## Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands  
Ferrari, Vittorio, Università 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**, Priyadarshini College of Engineering and Architecture, 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, 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 de La Salle, 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  
**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, 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  
**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 Ros, Juan Jose**, University of Cadiz, Spain  
**Granell, 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 Alcalá, Spain  
**Hernandez, Wilmar**, Universidad Politecnica de Madrid, Spain  
**Homentcovschi, Dorel**, SUNY Binghamton, USA  
**Horstman, Tom**, U.S. Automation Group, LLC, USA  
**Hsiai, Tzung (John)**, University of Southern California, USA  
**Huang, Jeng-Sheng**, Chung Yuan Christian University, Taiwan  
**Huang, Star**, National Tsing Hua University, Taiwan  
**Huang, Wei**, PSG Design Center, USA  
**Hui, David**, University of New Orleans, USA  
**Jaffrezic-Renault, Nicole**, Ecole Centrale de Lyon, France  
**Jaime Calvo-Galleg, Jaime**, Universidad de Salamanca, Spain  
**James, Daniel**, Griffith University, Australia  
**Janting, Jakob**, DELTA Danish Electronics, Denmark  
**Jiang, Liudi**, University of Southampton, UK  
**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

**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**, 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  
**Laurent, Francis**, IMEC, Belgium  
**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**, Michigan State University, 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  
**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  
**Mohamadi, Mohammad-Reza**, University of Cambridge, UK  
**Molina Flores, Esteban**, Benemirita Universidad Autonoma 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 Lahoucine**, 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  
**Pereira, Jose Miguel**, Instituto Politecnico de Seteбал, Portugal  
**Petsev, Dimitar**, 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  
**Reig, Candid**, University of Valencia, Spain  
**Restivo, Maria Teresa**, University of Porto, Portugal  
**Rezazadeh, Ghader**, Urmia University, Iran  
**Robert, Michel**, University Henri Poincare, France  
**Royo, Santiago**, Universitat Politecnica de Catalunya, Spain  
**Sadana, Ajit**, University of Mississippi, USA  
**Sandacci, Serghei**, Sensor Technology Ltd., UK  
**Sapozhnikova, Ksenia**, D.I.Mendeleyev Institute for Metrology, Russia  
**Saxena, Vibha**, Bhabha Atomic Research Centre, Mumbai, India  
**Schneider, John K.**, Ultra-Scan Corporation, USA  
**Seif, Selemeni**, 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  
**Slomovitz, Daniel**, UTE, Uruguay  
**Smith, Martin**, Open University, UK  
**Soleymanpour, Ahmad**, Damghan Basic Science University, Iran  
**Somani, Prakash R.**, Centre for Materials for Electronics Technology, India  
**Srinivas, Talabattula**, Indian Institute of Science, Bangalore, India  
**Srivastava, Arvind K.**, Northwestern University  
**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  
**Thumbavanam Pad, Kartik**, Carnegie Mellon University, USA  
**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, 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

# Contents

Volume 84  
Issue 10  
October 2007

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

ISSN 1726-5479

## Research Articles

- Programmable Solution for Solving Non-linearity Characteristics of Smart Sensor Applications**  
*S. Khan, I. Adam, Zahirul Alam, K. F. Mohd Suhut and N. Yusof*..... 1580
- Modeling of the Response of a Hot-Wire Anemometer with Neural Nets under Various Air Densities**  
*A. Al-Salaymeh and M. S. Ashhab*..... 1590
- A Genetic Algorithm for Optimization in Conceptual Design Phase of Robots**  
*Amir Jafari, Mohsen Safavi, Alireza Fadaei*..... 1607
- Uncertainty Analysis of Temperature Measurement System Using Interval Arithmetic**  
*B. Vasuki, M. Umopathy, S. Akhilan*..... 1619
- A Low-Power Signal Processing Unit for in vivo Monitoring and Transmission of Sensor Signals**  
*M. R. Haider, S. K. Islam and M. Zhang*..... 1625
- A Comparative Study of Fiber Optic Humidity Sensors Based on Chitosan and Agarose**  
*Jinesh Mathew, K. J. Thomas, V. P. N. Nampoori and P. Radhakrishnan*..... 1633
- Mechanical Behavior of a Thermal Micromirror Based on a Bimetallic Cantilever Beam**  
*Ghader Rezazadeh, Maliheh Pashapour, Leila Borghei*..... 1641
- Transformer Temperature Measurement Using Optical Fiber Based Microbend Sensor**  
*Deepika Yadav and A. K. Nadir*..... 1651
- MEMS Tunneling Micro Thermometer Based on Tip Deflection of Bimetallic Cantilever Beam**  
*Samrand K. Nezhadian, Ghader Rezazadeh, Shahram Kh. Arya*..... 1660
- A PC Based Level Indicating Controller Using a Hall Probe Sensor**  
*S. C. Bera, B. Chakraborty and D. N. Kole*..... 1669
- Model Based controller Design for a Shell and Tube Heat Exchanger**  
*S. Nithya, Abhay Singh Gour, N. Sivakumaran, T. K. Radhakrishnan and N. Anantharaman*..... 1677

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

## Programmable Solution for Solving Non-linearity Characteristics of Smart Sensor Applications

S. Khan, \*I. Adam, Zahirul Alam, \*K. F. Mohd Suhut and \*N. Yusof

International Islamic University, Malaysia, PO Box 10, Kuala Lumpur 50728

\* University Kuala Lumpur- British Malaysia Institute, Malaysia

E-mail: sheroz@iiu.edu.my, ismail\_adam@yahoo.com, kamal@bmi.edu.my, nhayati@bmi.edu.my

*Received: 13 April 2007 /Accepted: 23 October 2007 /Published: 30 October 2007*

---

**Abstract:** This paper presents a simple but programmable technique to solve the problem of non-linear characteristics of sensors used in more sensitive applications. The nonlinearity of the output response becomes a very sensitive issue in cases where a proportional increase in the physical quantity fails to bring about a proportional increase in the signal measured. The nonlinearity is addressed by using the interpolation method on the characteristics of a given sensor, approximating it to a set of tangent lines, the tangent points of which are recognized in the code of the processor by IF-THEN code. The method suggested here eliminates the use of external circuits for interfacing, and eases the programming burden on the processor at the cost of proportionally reduced memory requirements. The mathematically worked out results are compared with the simulation and experimental results for an IR sensor selected for the purpose and used for level measurement. This work will be of paramount importance and significance in applications where the controlled signal is required to follow the input signal precisely particularly in sensitive robotic applications. *Copyright © 2007 IFSA.*

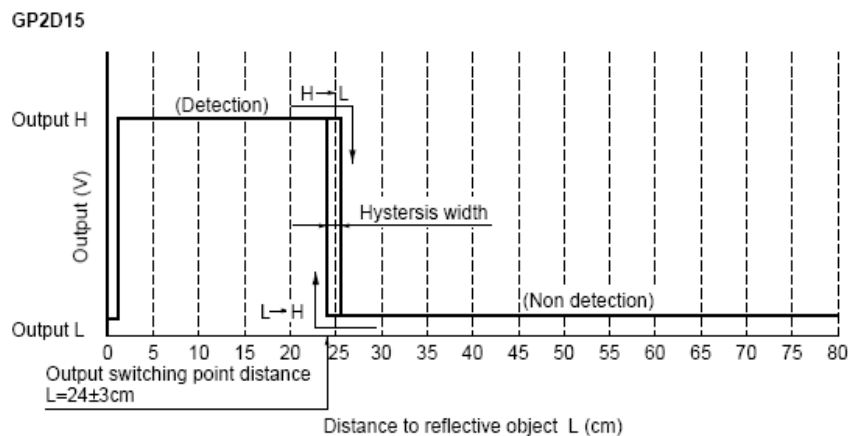
**Keywords:** Nonlinearity, Interpolation, Smart Sensors

---

### 1. Introduction

Sensing transducers work on the principle to give an output signal in response to changes in a physical input that is to be measured. A physical input may include things such as humidity, moisture content or pressure which are being monitored or used for controlling plants [1-3]. However, the output signal obtained suffers from the nonlinearity characteristics of sensors, making the designer to use additional circuits external to the main transducer for eliminating nonlinearities by one of the sensor

characterization methods. The nonlinearity will be of quite concerns in some applications, for example, any error in controlling the temperature of a boiler will obviously be disastrous, so is the case of robotic applications where wrongly made decisions for taking an onward step by a robot could become disaster in sensors measuring separation between objects or liquid levels. For separation and level measurement there are a number of sensors that are in use such as potential metric devices, capacitance, conductivity probes and ultrasonic devices. All such sensors besides having their own advantages are associated with the concerns of more careful design requirements and the requirement of complicated signal conditioning circuitry to combat the concerns of sensor nonlinearity [4-5]. In some other solutions digital signal processing techniques and other compensation methods are used [6-7]. The technique suggested here in this work is shown for two sensors, the digital output sensor (GP2D15) and the analogue output sensor (GP2D12) [8] with their responses shown in Fig. 1 and Fig. 2 respectively. In many applications, the capability of the analogue output infra red sensor (GP2D12) is not fully exploited. The capability of analogue output infra red sensor (GP2D12) to sense the gradual change of distance is overlooked, and hence is less commonly used compared to its sibling digital output infra red sensor (GP2D15), which gained comparatively more popularity for applications in industry. The inappropriate justification on choosing between these two different sensors is mainly due to two factors--- the designer is only looking for a sensor whose output can be varied within the specified range such in robotic applications, and secondly due to the failure of GP2D12 on dealing with the nonlinearity issue which limits its range of applications.



**Fig. 1.** GP2D15 Output Response by SHARP.

The linearity problem is solved by representing the given response curve through a set of lines drawn manually and tangent to the curve at selected points. The microcontroller in use is programmed for making exclusive jumps among the equations for choosing one of the tangents that closely fits to the voltage input sensed at one of the analogue pins. Hence choosing an equation is equivalent to choosing the corresponding proportional output value. The results of manually calculated distances are compared with a simulation results obtained through using PIC IDE Simulator. The effect of increasing the number of equations is studied to have a favourable effect on the output without sacrificing speed and memory compromises.

Most of the data acquisition systems are microcontrollers-based with input connected to built-in Analog-to-Digital converter (ADC) and pulse width modulated (PWM) outputs. Our work in this suggestion is based on its comparison with the one which is already suggested in [9] which requires additional circuit requirements external to the microcontroller-based transducer for programming the microcontroller in order to make the external circuit help in linearization of the sensor output response. This method is causing two major concerns -- space and cost requirement. Further it comes with the

sacrifice of time and memory requirement in the form of code for making the initial checks on the input in the light of comparisons made by the resistor divider. The work suggested here is program the microcontroller with C language in the light of some manual calculations done manually to the response curve of the infra red distance sensor thus lending itself to many robotic and other related applications where precision in distance measurements is of critical importance.

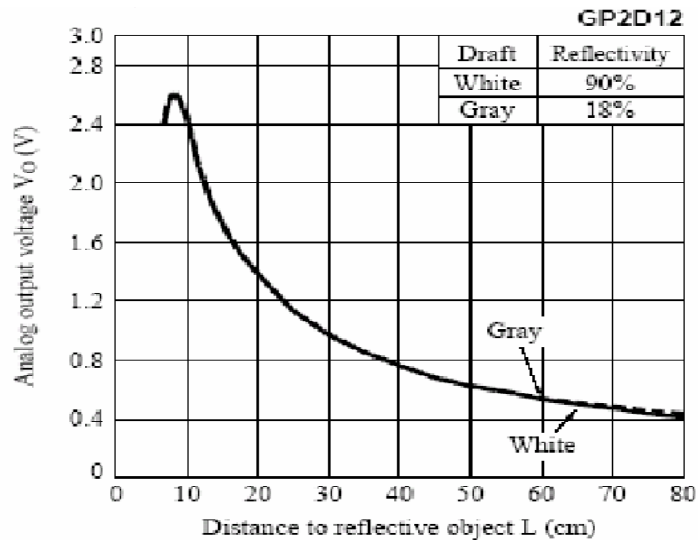


Fig. 2. GP2D12 Output Response – Provided by SHARP.

## 2. Popular Technique in Solving the Non-linearity Issue

Fig. 3 shows the output response of a GP2D12 analogue output sensor with respect to the distance of an object from its shutter. Tangent lines are drawn manually at selected points as shown in Fig. 3 to represent the given graph as a set of straight tangent lines with each line given by  $y = mx + c$ , with ' $m$ ' being the gradient and ' $c$ ' as the y intercept ' $x$ ' of the tangent line respectively.

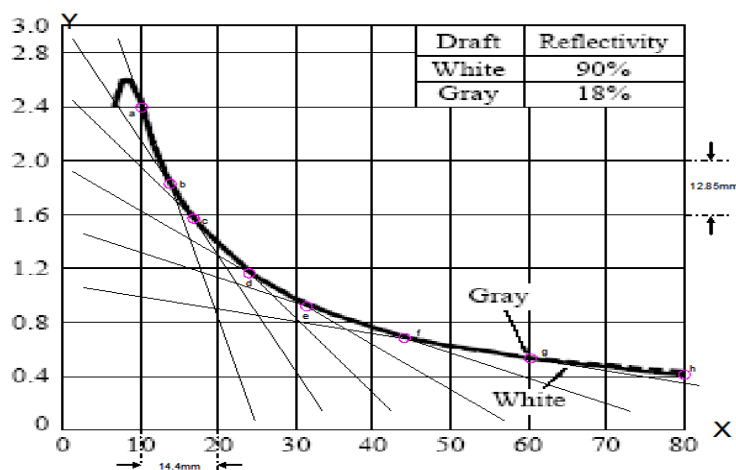


Fig. 3. Number of Tangent Lines Drawn on the Response Graph.

This technique yields distance ' $x$ ' given by  $x=(y-c)/m$  for a sensed input value of ' $y$ ' volts. Though the theory is quite simple, its practical implementation is a challenging task due to a number of ' $c$ ' values

that must be measured from the nonlinear response graph given which leads to multiplication of final system errors. For this reason, a lot of designers used the table look up method to solve such problem by pre-programming the output data of distance  $x$  stored in ROM. However, the method in this work significantly differs in that a simple program is developed to getting in order by a given pointer data of the sensed voltage 'y' that is being read by sensor from the memory. This is where this programming saves memory space which seems to be comfortably practical and economical in many applications.

### 3. Solving the Non-linearity Response by Interpolation

In Fig. 2 shows tangent lines are drawn on the output response of GP2D12. They are arranged in a manner that all points on non-linear graph, important from sensitivity view point, are covered by these tangent lines. The coordinates of the points at which tangent lines touch the curve are found by measuring their vertical from the x-axis and horizontal distance from the y-axis. The coordinates so calculated are tabulated in Table 1. For example, at point (e) the distance of the coordinate in horizontal to y axis is 45mm. If it is divided by 14.4 mm and multiplied by 10 cm, resolved 31.25cm; and the distance of the coordinate to x axis is 29.6mm. By dividing 29.6 mm with 12.85mm and multiplying it with 0.4 volt, the result if 0.92 volt is archived. All the calculated coordinates were tabulated in Table 1.

**Table 1.** Table of Coordinates derived from Fig. 3.

Point	a	b	c	d	e	f	g	h
X	10.00	13.89	16.67	23.94	31.25	43.82	60.00	80.00
Y	02.40	01.83	01.57	01.17	00.92	00.68	00.53	00.41

The interpolation technique is used to estimate the unknown point between the given two known points. The function is formed by the two known points, and simpler to be solved in such linear problem as only two points are required to perform the exact calculation. For two known points  $(x_0, y_0)$  and  $(x_1, y_1)$ , the equation of interpolation for calculating the x-coordinate of an unknown point in terms of its corresponding y-coordinate is given by  $x_b = x_0 + \frac{[y_b - y_0]}{[y_1 - y_0]} \times [x_1 - x_0]$ . By putting into this equation the coordinates provided in Table 1, the corresponding equations are as listed in Table 2 for using in the programming code of the microcontroller.

**Table 2.** Equations Deduced from Coordinate listed in Table 1.

Range of $y_b$	Distance measured by the sensor ( $x_b$ )	Equation
1.83-2.40	$26.37895 - y_b \times 6.82456$	1
1.57-1.83	$33.4569 - y_b \times 10.6923$	2
1.17-1.57	$45.20475 - y_b \times 18.175$	3
0.92-1.17	$58.1508 - y_b \times 29.24$	4
0.68-0.92	$79.435 - y_b \times 52.375$	5
0.53-0.68	$117.16933 - y_b \times 107.867$	6
0.41-0.53	$148.3333 - y_b \times 166.667$	7

#### 4. Source Code Development

The microcontroller (MICROCHIP PIC16F877A) with a built-in analogue to digital converter is used along with a (2 x 16) Liquid Crystal Display (LCD) for the practical implementation of the technique mentioned above [10]. The Embedded C compiler from Custom Computer Services (CCS) is used for developing the implementation source code for the system. The program is simpler and easy to be developed compared to the tedious assembly language. The flow-chart for developing the source is shown in Fig. 4.

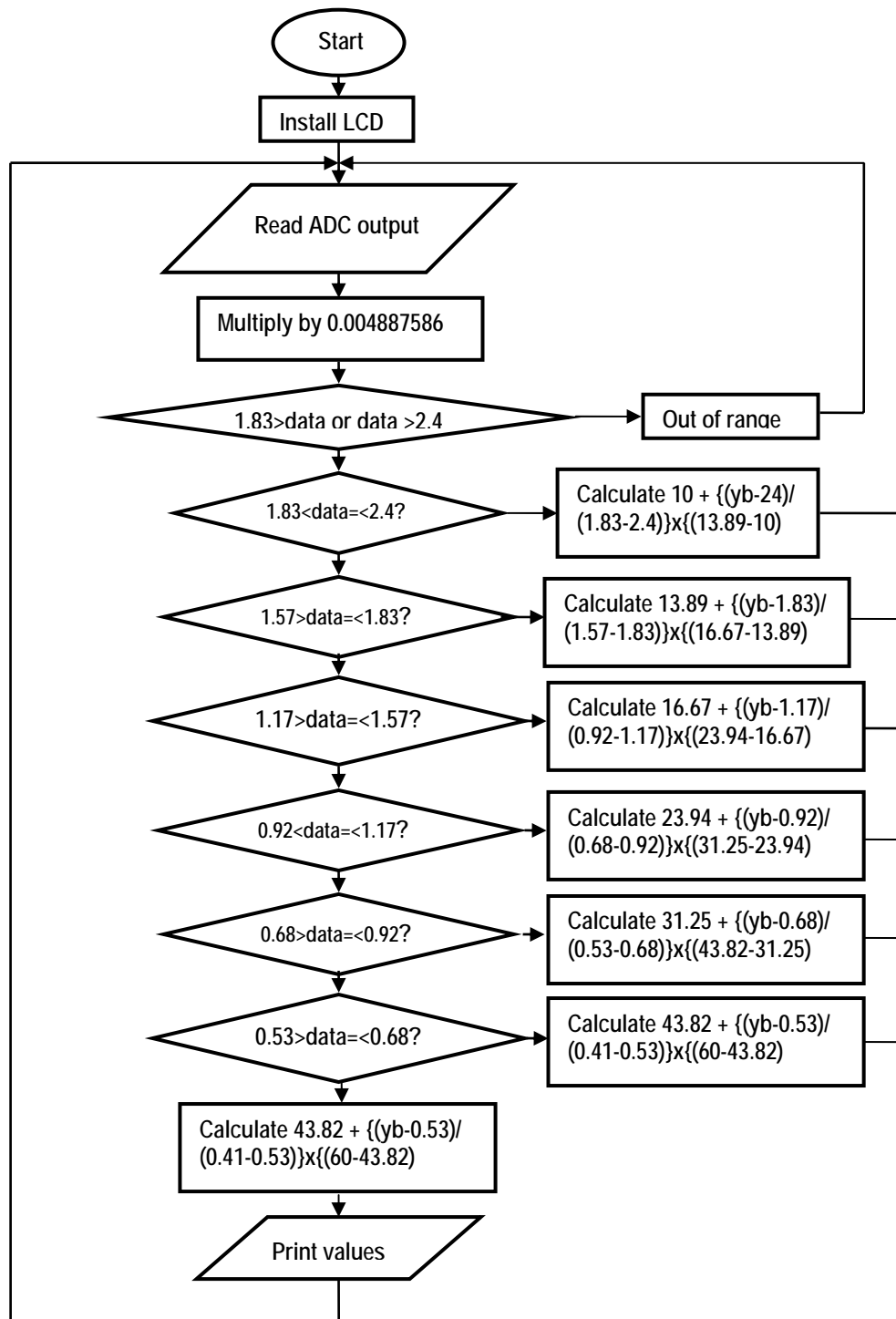


Fig. 4. Source code flow-chart.

The program starts by initializing all the input/output ports, the intended registers and the LCD. Then the processor reads the sensed voltage through the ADC channel 0 (PIN 1). The digital voltage is further converted to analogue voltage by using 
$$volt (ana) = \frac{volt (dig) \times 5}{1023}$$
.

The result of the conversion is tested using IF-ELSE statements in the code to decide on which of the seven equations will be relevant to be used depending on what is given in Table 2. For input voltage falling out of the available range (0.41 to 2.4 V), the system prompts back to the user a message such as, while for an input voltage 'Out of Range', while the system displays the permissible range for a maximum distance of 10 cm.

## 5. Simulation and Verification

In order to verify the equations discussed in the previous section, the manual calculation are done for all the seven test points. For that purpose, the value inserted  $y_b$  is ensured to fall in the range covered by each equation selected. The results were compared to the results generated by the PIC IDE Simulator from Oshon Software. The simulation is done by converting the analogue input to digital and feed the value into the PIC IDE Simulator and the simulation window is shown in Fig. 5.

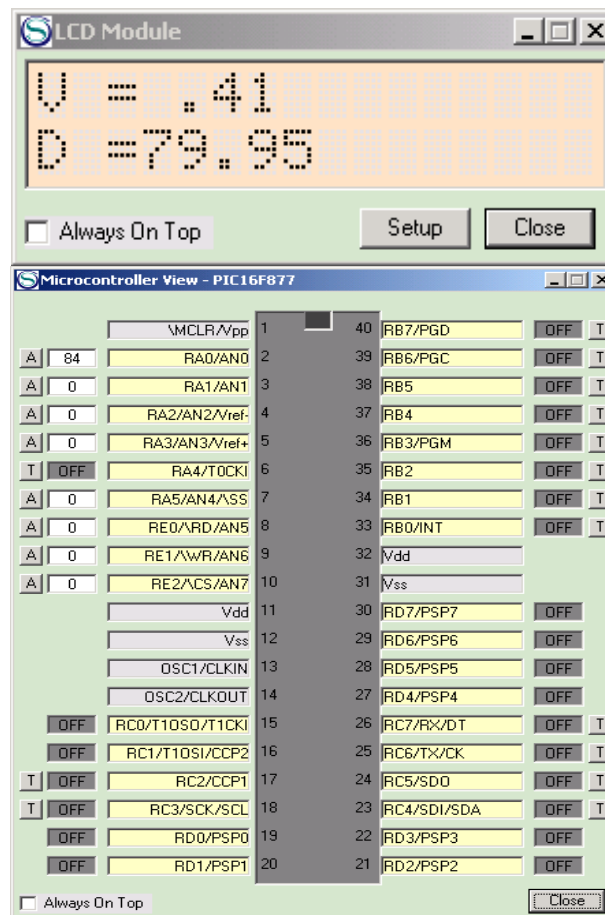


Fig. 5. Simulation using PIC IDE Simulator.

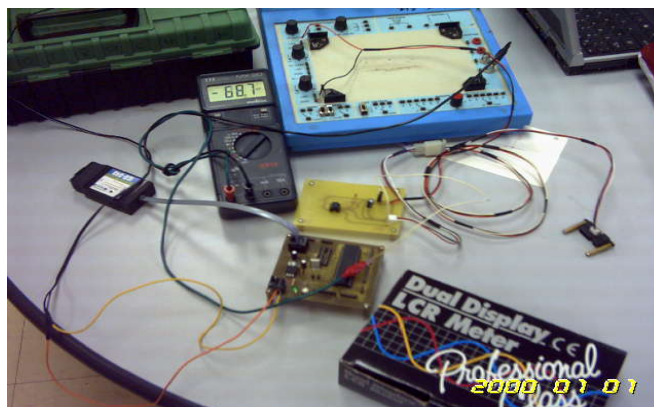
The corresponding manual calculations and comparisons are given in Table 3, where from the seven test points the maximum error between the simulation and the calculation is found to be 0.12 cm

**Table 3.** Equations and Simulation Derived Values for Errors Calculations.

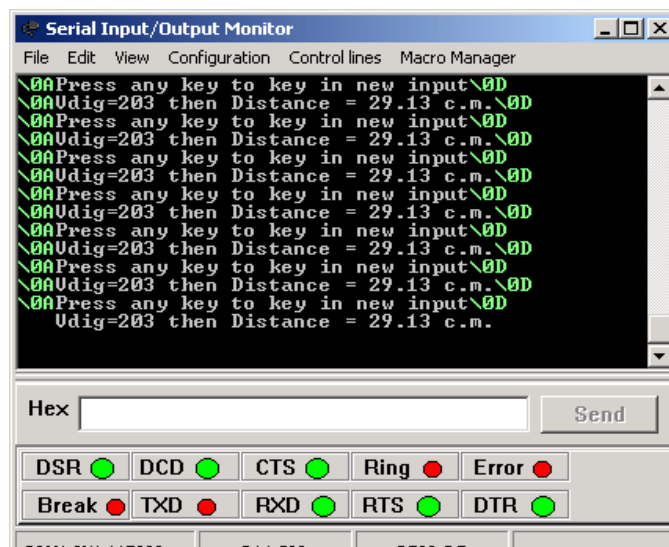
Input $y_b$	Equation Value	Simulation	Error
2.10	$26.37895 - y_b \times 6.82456 = 26.37895 - 2.1 \times 6.82456 = 12.047374$	12.03 cm	0.02 cm
1.60	$33.4569 - y_b \times 10.6923 = 33.4569 - 1.6 \times 10.6923 = 16.34922$	16.36 cm	0.01 cm
1.40	$45.20475 - y_b \times 18.175 = 45.20475 - 1.4 \times 18.175 = 19.75975$	19.79 cm	0.03 cm
1.00	$58.1508 - y_b \times 29.24 = 58.1508 - 1 \times 29.24 = 28.9108$	28.85 cm	0.06 cm
0.80	$79.435 - y_b \times 52.375 = 79.435 - 0.8 \times 52.375 = 37.535$	37.45 cm	0.08 cm
0.60	$117.16933 - y_b \times 107.867 = 117.16933 - 0.6 \times 107.867 = 52.44913$	52.32 cm	0.12 cm
0.45	$148.3333 - y_b \times 166.667 = 148.3333 - 0.45 \times 166.667 = 73.33285$	73.44 cm	0.09 cm

## 6. Final Testing

Finally, the experiment is conducted by developing the special program that is able to interact with the user through the serial port for data entry and display. Fig. 6 shows the experimental set up, where the input represent the digital voltage that is ranging from 0 up to 1023 which are equivalent to 0 volt up to 5 volt. The serial input/output watch (SIOW) from CCS Compiler as shown in Fig. 6 is used to key in the input and display the data received.

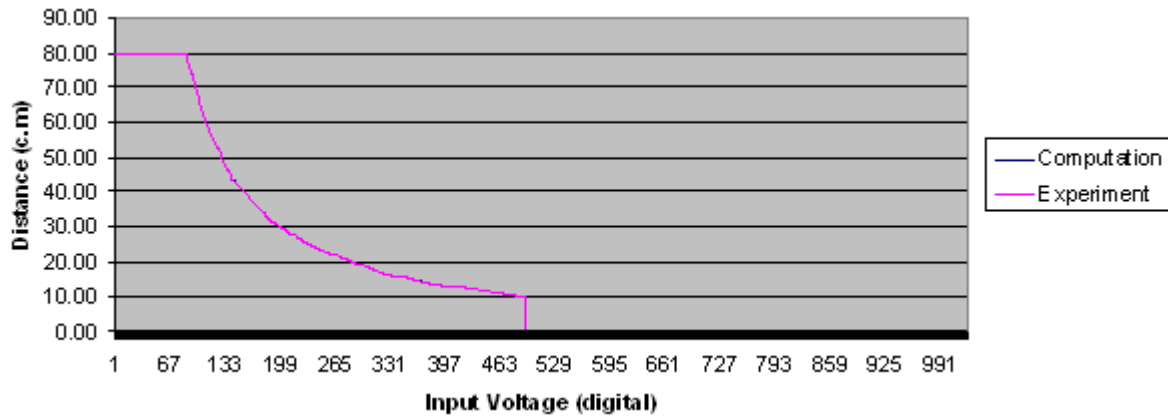


**Fig. 6.** Experimental set up.

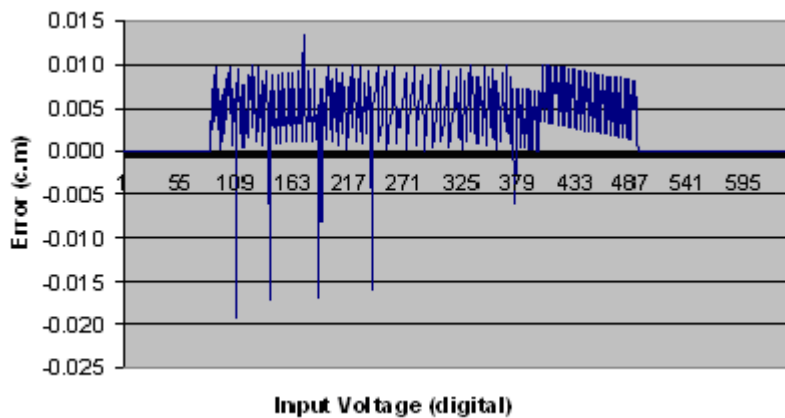


**Fig. 6.** The SIOW interface.

In response to the input entered, the microcontroller accordingly calculates the corresponding analogue voltage and resultant distance prior to its transfer to a personal computer for display. The results are tabulated in Microsoft Excel spread sheet and again compared to the computational result of the corresponding data. The error of the experimental and the calculation values is  $\pm 0.02$  cm or  $\pm 0.2$  mm. Fig. 7 shows the results of the experiment and calculation while Fig. 8 shows the error between the computational and experimental results.



**Fig. 7.** Experimental and Computational Results.



**Fig. 8.** Error between the Experimental and Computational Results.

The time taken by the microprocessor to solve the above technique is also measured by letting the bit 7 of port B high during the execution of the function. The time taken for the bit to be at high has been measured using oscilloscope to be at 4.86 milliseconds per execution with the operating frequency of 20 MHz. In overall, the sensor produced a precise output with the maximum error of  $\pm 0.2$  millimetres. If implemented with MICROCHIP PIC16F877A, it requires about 24% of ROM and 16% of RAM, which is equivalent to about 2 K byte. This proves the excellence of the technique suggested for the solution of non-linearity problem with sensors fro smart applications at the cost of a bit of time taken.

## 7. Conclusions

The level and distance measurement project by using the GP2D12 SHARP distance sensor has been tested and verified to be as expected. It proved that the proposed simple method and procedure applied

to develop the project is applicable in solving the nonlinear response of smart sensor applications. The simple implementation and progressively diminishing error make it really suitable for number of precise measurement applications. In addition this method eliminates the chances of errors as a result of external circuitry due to degradation and environmental damage as a result of result of temperature and physical contacts.

## **Acknowledgements**

The authors acknowledge the technical support of staff of both of the universities of the authors, particularly that of Raman AKOH and Zaihas Hafzan Amri for conducting the performance measurement tests. Thanks to the Ministry of Science, Technology, and Innovation Malaysia (MOSTI) financial support through IRPA grant No. IRPA Project No: 03-02-08-0307-EA003.

## **References**

- [1]. Curtis D. Johnson, *Process Control Instrumentation Technology*, Prentice Hall College Division, 1996.
- [2]. James R. Carstens, *Electrical Sensors and Transducers*, 1<sup>st</sup> Edition, Regents/Prentice Hall, 1993.
- [3]. Peter Elgar, *Sensors for Measurement and Control*, 1<sup>st</sup> Edition, Prentice Hall, 1998.
- [4]. Data Sheet – GP2D12 (2005, January 12). [Online]. Available: <http://www.activerobots.com/products/sensors/sensors-sharp.shtml>
- [5]. G. Bucci, M. Faccio, and C. Landi, The Implementation of Smart Sensor Based on a Piece Linear A/D Converter, *IEEE Instrum. Meas. Technol. Conf.*, St Paul, MN, 1998, pp. 1223-1228.
- [6]. G. Bucci, M. Faccio, and C. Landi, New ADC with piecewise linear characteristic: case study - implementation of a smart humidity sensor, *IEEE Trans. Instrum. Meas.*, Vol. 49, No. 6, Dec. 2000, pp. 1154-1166.
- [7]. G. H. Iglesias and E. A. Iglesias, Linearization of transducers signals using analog-to-digital converter, *IEEE Trans. Instrum. Meas.*, Vol. 37, No. 1, March 1988, pp. 53-57.
- [8]. Data Sheet – GP2D12 (2005, January 12). [Online]. Available: <http://www.activerobots.com/products/sensors/sensors-sharp.shtml>
- [9]. J. M. Dias Pereira, Octavian Postolache, and P. M. B. Silva Girao, A Digitally Programmable A/D Converter for Smart Sensor Applications, *IEEE Trans. Instrum. Meas.*, Vol. 56, No. 1, February 2007, pp. 158-163.
- [10]. Data Sheet – PIC16F87X (2001). [Online]. Available: <http://www.microchip.com/>
- [11]. Richard Barnett, Sarah Cox and Larry O’Cull, *Embedded C Programming and the Microchip PIC*, 1<sup>st</sup> Edition, Delmar Learning, 2004.



Advanced  
Environmental  
Monitoring  
Research  
Center (ADEMRC)

## Call for Papers The First Announcement

Gwangju  
Institute of  
Science and  
Technology



# The 7<sup>th</sup> International Symposium on Advanced Environmental Monitoring



February 25-28, 2008  
East-West Center  
Honolulu, HI, USA

Organized by  
GIST/ADEMRC



### Abstract Submission

The deadline for abstract  
submission is  
**September 15, 2007**  
The abstract should be  
written in MS Word format.

#### ● Abstract Submission

You are invited to submit short abstracts for the "7<sup>th</sup> International Symposium on Advanced Environmental Monitoring". To have your abstract considered for oral or poster presentation at the symposium, submit the abstract and author information form through symposium web-site; [http://ademrc.gist.ac.kr/7th\\_sym](http://ademrc.gist.ac.kr/7th_sym).

#### ● Technical Program

The 2008 ADEMRC symposium technical program will be developed from both submitted and solicited papers. Presentation format will include oral and poster technical sessions.

#### ● Venue

The symposium will take place at the **Hawaii Imin International Conference Center** on the **East-West Center** campus. The East-West center is located in Honolulu, three miles from Waikiki and adjacent to the University of Hawaii.

#### ● Symposium Topics

- Atmospheric Environment Monitoring
  - Optical atmospheric environment monitoring
  - Remote sensing of atmospheric environment
  - Monitoring and modeling of trace air pollutants
- Contaminants Control Process Monitoring
  - Biological wastewater process monitoring
  - NOM & DBPs monitoring
  - Soil environment & remediation monitoring
- Environmental Toxicity Monitoring and Assessments
  - Toxicity monitoring & bio-sensors
  - Biological and chemical monitoring of environmental toxicity

#### ● Technical Tour

- NOAA Mauna Loa Observatory
- National Renewable Energy Laboratory (NREL)

#### ● Science & Program Committee

Prof. Young J. Kim, GIST, Korea, Symposium Chair  
Prof. Ulrich Platt, Univ. of Heidelberg, Germany  
Prof. Man Bock Gu, Korea University, Korea  
Prof. Peter D. Hansen, Technical Univ. of Berlin, Germany  
Prof. In Soo Kim, GIST, Korea  
Dr. Russ Schnell, NOAA, USA  
Prof. Shimshon Belkin, Hebrew Univ. of Jerusalem, Israel  
Dr. Histosh Iwahashi, AIST, Japan

#### ● Registration Information

- [Pre-registration available at web-site](#)
- [On-line abstract submission](#)

Advanced Environmental Monitoring Research Center (ADEMRC)  
Gwangju Institute of Science & Technology (GIST), Gwangju, Korea

E-mail: [sympo@gist.ac.kr](mailto:sympo@gist.ac.kr) | PHONE: +82-62-970-3402~3 | Fax: +82-62-970-3404

## 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

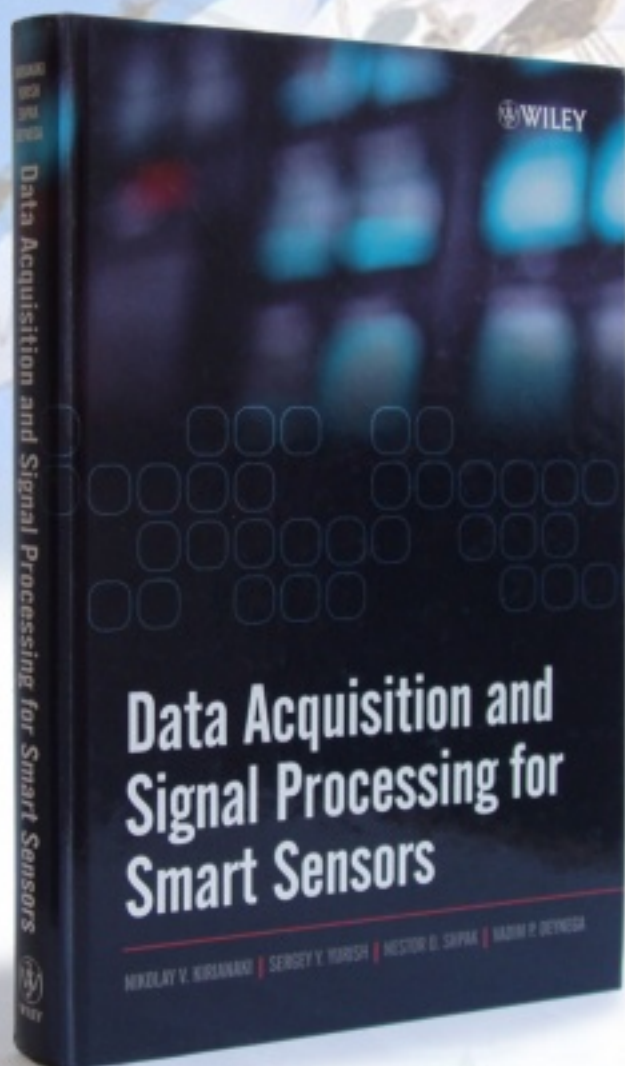
Articles should be written in English. Authors are invited to submit by e-mail [editor@sensorsportal.com](mailto:editor@sensorsportal.com) 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation 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](mailto:sales@sensorsportal.com) Please download also our media kit: [http://www.sensorsportal.com/DOWNLOADS/Media\\_Kit\\_2007.PDF](http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2007.PDF)



KNOWLEDGE FOR GENERATIONS



**'This book provides a good basis for anyone entering or studying the field of smart sensors not only for the inexperienced but also very useful to those with some experience'**

*(from IEEE Instrumentation & Measurement Magazine review)*



**Order online:**

**[http://www.sensorsportal.com/HTML/BOOKSTORE/DAQ\\_SP.htm](http://www.sensorsportal.com/HTML/BOOKSTORE/DAQ_SP.htm)**

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