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Biogas Analyzer Based on Open Source Hardware: Design and Prototype Implementation

Antonio José Calderón and Isaías González
Department of Electrical, Electronic and Automatic Engineering, University of Extremadura,
Avenida de Elvas, s/n, 06006 Badajoz, Spain
Tel.: +34-924-289-600
E-mail: ajcalde@unex.es, igonzp@unex.es

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Abstract: The main objective of this paper is the development of a device similar to a continuous gas sensor, which can analyze the composition of combustible gases, depending on the types of sensors installed in the capsule designed for this purpose. Some manufacturers of continuous gas analyzers provide equipment with high price. The goal of this work is the design and prototype implementation of a low cost system, affordable to any type of company, based on the platform Open Source Hardware Arduino, for measuring and analyzing biogas. This system can be used for many applications and because biogas is a renewable gas fuel, it will be increasingly important in countries committed to the reduction of greenhouse gases. All circuits will be designed and later simulated with the software Multisim 14.0. The printed circuit boards will be created with the help of the software Ultiboard 12.0 and, finally, the necessary files will be created for the printing of these circuits in the plates with the software LPKF CircuitPro 1.5. The developed prototype is described as well as the main conclusions of the work.

Keywords: Continuous analyzer, Combustible gases, Biogas, Open source hardware, Arduino, Low cost.

1. Introduction

Continuous gas analyzers are equipment that analyzes the composition of gases continuously. That is, as the gas is flowing through the analyzer, the reading of the gas composition can be instantly obtained. As aforementioned, the idea is to develop a system to measure and analyze the composition of gases continuously, in this case biogas, by a low cost and open source hardware acquisition system, as Arduino. This system will include a data reading system based on a LCD display and the possibility of sharing information with other devices using the well-known Modbus industrial protocol.

Focusing on combustible gases, these are used for the production of thermal energy from a combustion process. Some gases of this type are natural hydrocarbons and those manufactured solely for use as fuel. Among all possible cases, it has been decided to develop a prototype to determine the composition of biogas. Biogas can be generated in natural media or in a sealed, oxygen-free tank called anaerobic digester, from the reactions of biodegradation that are produced of the organic matter, by the action of microorganisms in the absence of oxygen [1]. In this sense, one of the great advantages of biogas is that this fuel is generated by the disposal of waste

The composition of this combustible gas varies according to the origin of the same [2]. This combustible gas consists of a mixture composed of 50-70 % of methane (CH_4) and 30-50 % of carbon dioxide (CO_2). It also contains minimal amounts of

other gases, such as nitrogen (N_2), hydrogen sulfide (H_2S), and some traces of water vapor. The calorific value of the biogas will vary its value depending on the proportion of methane in the mixture [3].

Measuring and monitoring a number of magnitudes is an inherent part of scientific and technologic activities. The term data acquisition system (DAQ) is often applied to a variety of measures, ranging from analog to digital signals of several types [4]. To implement a DAQ, it is pertinent to mention that different open source hardware platforms have appeared during last years like Arduino [5], RaspberryPi [6], Intel Edison [7] and openDAQ [8]. Precisely, Arduino is a low-cost single-board microcontroller which has become a versatile and powerful tool to develop different applications in the fields of data acquisition, automation and engineering in general [9]. As DAQ, Arduino has been recently reported in scientific literature for fuel cell-based systems [9], for networked handling of sensors and actuators [10], for detection of pests and plant damage [11], for indoor and outdoor gas sensing [12], for air quality monitoring [13], for meteorological measurements [14] and for biomedical vital signs acquisition [15].

The measurement system designed in this work is based on four sensors that have been chosen according to the requirements of the company that collaborates with the university to develop this prototype. However, it can be extrapolated to any other type of gas simply modifying the set of selected sensors. This paper is an extended version of the contribution [16].

The rest of this paper is organized as follows. Section 2 gives some details of the chosen sensors for measuring the concentration of the selected gases according to the company prescriptions. Section 3 describes the design and implementation of the auxiliary electronic circuits and the design of the DAQ based on an Arduino board, used for collecting the data of the set of sensors. In Section 4 Preliminary experimental results of the system working under laboratory conditions will be shown. The conclusions close the article.

2. Sensors for Combustible Gases

Regarding the monitoring of combustible gases, sensors are required that can detect high concentrations of gases, compared to those required for toxic gases that must be more sensitive to lower levels of concentrations.

For both cases, can be considered five types of sensors, each based on a different foundation for the detection of different gases, namely electrolytic sensors, catalytic sensors, solid state sensors, infrared sensors and photoionization detectors.

Among all types of gas sensors, semiconductor type sensors have been chosen. These sensors have a thin film of metal oxide, on which a piece of silicone is deposited. The absorption of gas at the surface with this oxide results in a change in the electrical resistance, which is related to the measured gas concentration of the sample. In the presence of gas, the metal oxide causes the gas to dissociate into charged ions or complexes which results in the transfer of electrons. This kind of sensors have a built in heater, which heats the metal oxide material to an operational temperature range that is optimal for the gas to be detected. This heater is regulated and controlled by a specific circuit (Fig. 1.).

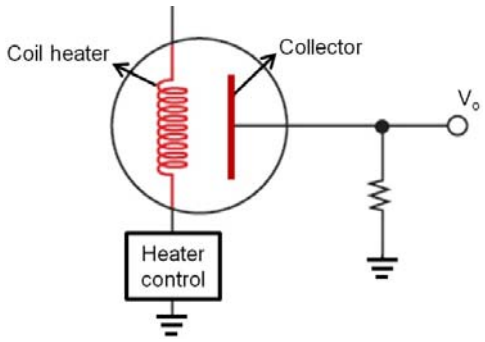


Fig. 1. Diagram of semiconductor type sensors for gas sensing.

For the implementation of the biogas measurement prototype, the gases whose concentration is sensed are: ammonia, carbon monoxide, hydrogen and methane. The selected sensors to carry out this analyzer have been bought to the same manufacturer [17]. Table 1 depicts the measured gas, the associated sensor model and the concentration range.

Table 1. Measured gas, sensor model and concentration range of the prototype.

Measured gas	Sensor model	Concentration range
Ammonia	TGS2444	10-300 ppm
Carbon monoxide	TGS5042	0-1000 ppm
Hydrogen	TGS821	10-5000 ppm
Methane	TGS3870	1000-9000 ppm

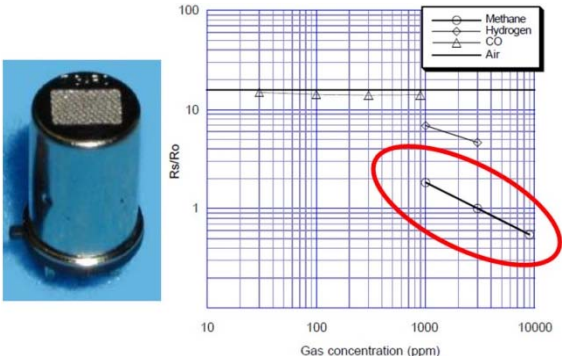
Fig. 2 shows a snapshot of each sensor jointly with the characteristic curve used for the design, extracted from their datasheets.

Fig. 3 depicts the sensors selected along with their interface circuitry, developed as will be described in the next section.

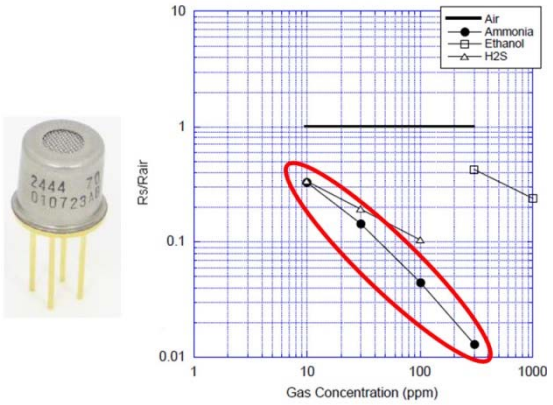
3. Development of the Prototype

This section deals with the design and theoretical development of all the circuits involved in the biogas measurement system. To develop this project, a series of auxiliary electronic circuits are needed to make the sensors work. These auxiliary circuits are responsible for the generation of pulses, amplification of signals and sampling of the latter. In each case, the

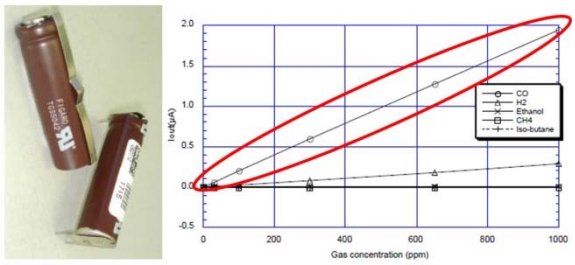
specifications supplied by the manufacturer have to be taken into account to determine the value of the circuits' components.



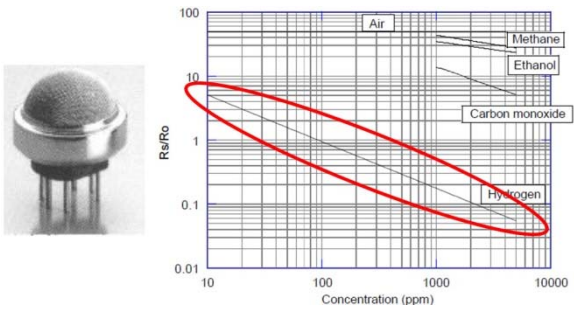
(a)



(b)

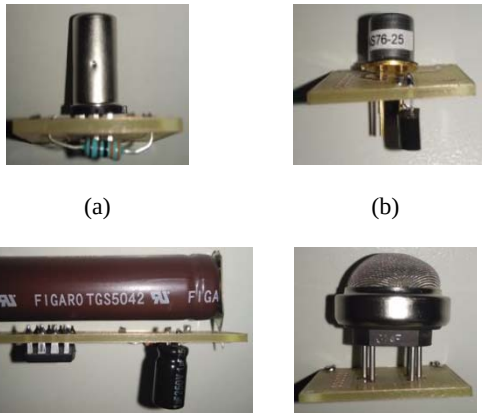


(c)



(d)

Fig. 2. Snapshot of each sensor and the corresponding curve: a) Methane; b) Ammonia; c) Carbon monoxide; d) Hydrogen.



(a) (b) (c) (d)

Fig. 3. Sensors along with their interface circuitry: a) Methane; b) Ammonia; c) Carbon monoxide; d) Hydrogen.

For example, in the case of the methane sensor, this one requires two voltages: a heater voltage (V_H) and a circuit voltage (V_C). The heater voltage is compulsory to maintain the sensing element at specific temperatures which are optimal for sensing two different gases. So, heater voltages of 0.9 V and 0.2 V are alternatively applied during a 20 seconds heating cycle. For the generation of the necessary pulses in the case of methane, we have chosen a microcontroller PIC 10f200. This one will generate the pulses V_C and V_H shown in Fig. 4. As seen in this figure, the pulse V_H goes from 0 to 5 s. For the pulse V_C, as it is desired to measure methane (CH_4), the pulse goes from the instant 4985 ms to 4990 ms.

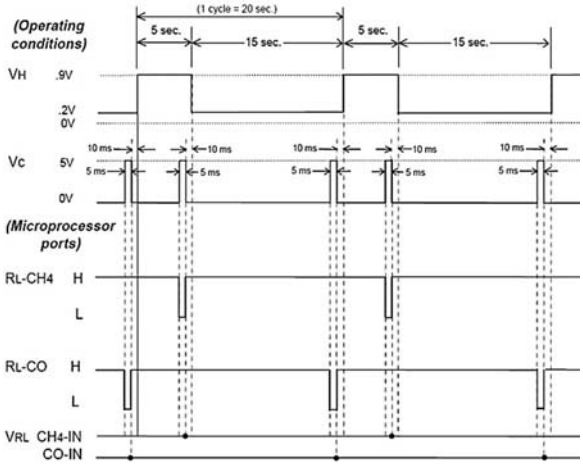


Fig. 4. Pulse generation for methane sensor using the PIC 10f200.

In order to implement the electronic circuits of the sensors in a faster and easier way, the software contained in the National Instruments (NI) Circuit Design Suite 14 package will be used. It includes the Multisim software 14.0 that will be used for the assembly and simulation of the electronic circuits, defined theoretically.

For programming the PIC 10f200 microcontrollers, the software of the manufacturer of this hardware, MPLAB X IDE v3.60, will be used with the compiler XC8 v1.42, which allows us to program these micro-controllers in a high-level language such as C. Fig. 5 shows the complete circuit including the methane sensor model (highlighted in blue).

The output V_{RS} of the sensor is connected to the input of a closed loop operational amplifier in non-inverting configuration. In this case the Instrumentation Amplifier is an AD708JN which has a gain:

$$G = 1 + \frac{R4}{R2}, \quad (1)$$

to be able to adjust the output to the 0-5 V range. Subsequently, the output of the Instrumentation Amplifier is taken to the sample and hold circuit that will maintain a constant output during the entire sensor period.

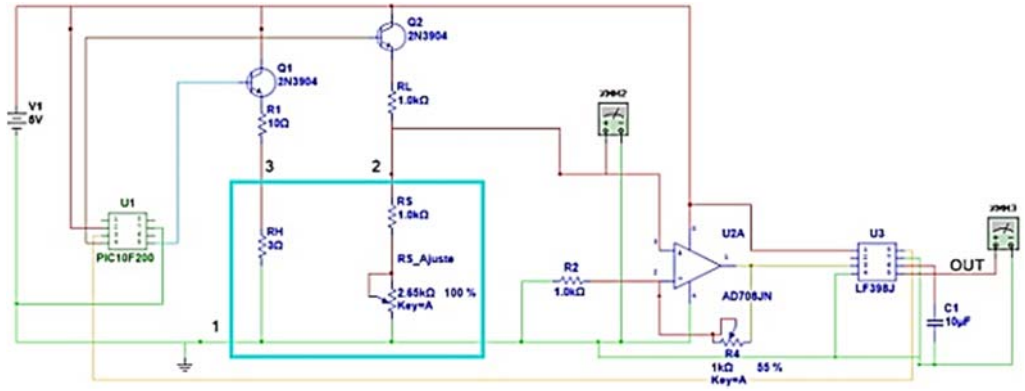
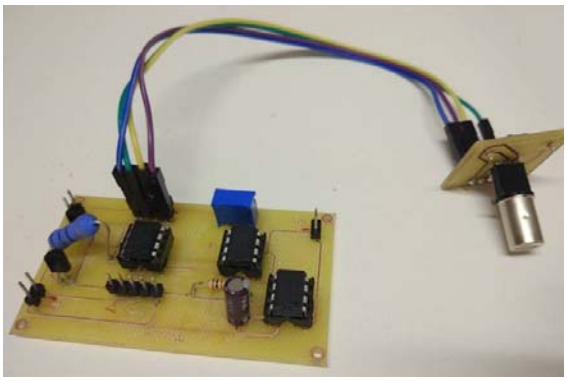


Fig. 5. Circuitry for the methane sensor in NI Multisim environment.

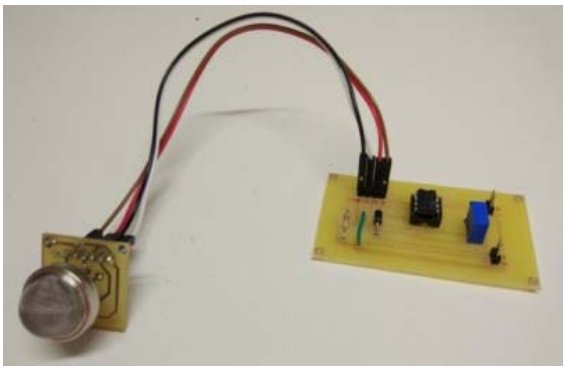
In order to simulate the TGS 3870 sensor, a model with fixed and variable resistors has been created.

The designs made in Multisim have been exported to Ultiboard to create the Printed Circuit Boards (PCBs). Printed circuit boards will be created with the help of Ultiboard 12.0 software. Finally, the necessary files will be created for the machine responsible for printing these circuits on the plates with the LPKF CircuitPro 1.5 software [18]. The final assembly of the sensors with their electronics on the corresponding PCB is shown in Fig. 6.

In this research, an Arduino board, model MEGA2560 has been used as DAQ for the set of sensors. It is based on a microcontroller ATmega2560. It has 54 digital input/output, 16 analog inputs, 4 UARTs, a 16 MHz crystal oscillator, a USB connection, a power jack, an In Chip Serial Programmer (ICSP) header and a reset button. With this microcontroller we can read the data, display it on the screen, using a graphic display LCD, and share it with other devices using ModBus. Analogue input channels are used to measure the voltage of the output circuits of the sensors. The display used is a 128×64 Graphic LCD with an ST7920 controller. In order to use the ModBus TCP/IP protocol, an Ethernet Shield HanRun HR911105A is devoted. To carry out the connection between the Arduino with the display and with the Ethernet shield, the SPI (Serial Peripheral Interface) protocol is used. The open-source Arduino Integrated Development Environment (IDE) has been used to program the microcontroller. This software makes easy to write code and upload it to the board. Open source libraries have been used to control the modules used (Ethernet and GLCD).



(a)



(b)

Fig. 6. Final assembly of sensors and electronics: a) Methane sensor; b) Hydrogen sensor.

The cost of Arduino MEGA is noticeably lower than the cost of a traditional DAQ. The carbon

monoxide sensor is the cheapest, 28 €, whereas the ammonia sensor costs 90 €. The system total cost is about 300 €. The cost of the Arduino board is 40 €. A DAQ with analog inputs costs over 450 € in the market, so the low cost character of the proposal is clearly stated.

Fig. 7 shows the hardware implementation of the DAQ system.

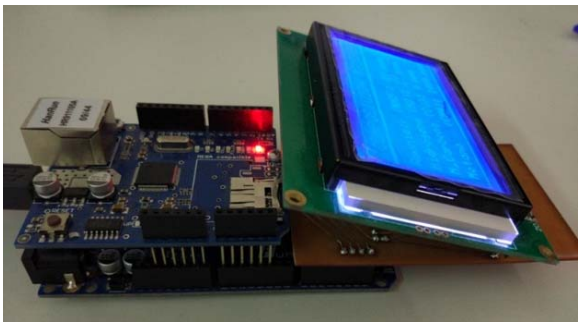


Fig. 7. Hardware setup of the developed prototype.

A methacrylate capsule has been designed with Autodesk AutoCad 2013 and Autodesk Inventor 2014 software, which will circulate the biogas to analyze and house the sensors used (Fig. 8). The chosen sensors can be observed once mounted in the capsule.



Fig. 8. Methacrylate capsule containing the sensors.

For a clearer exposition, Table 2 summarizes the diverse software packages used for the prototype development.

Table 2. Software packages used to develop the prototype.

Software package	Developed task
Arduino IDE	Code generation for Arduino
Microchip MPLAB X	Code generation for PIC
NI Multisim	Design and simulation of electronic circuits
NI Ultiboard	Design of PCBs
LPKF CircuitPro	Physical realization of PCBs
AutoCad 2013 & Autodesk Inventor	Design methacrylate capsule

4. Preliminary Experimental Results

As previously commented, the developed prototype is still under validation and assessment. However, as sample of the achieved experimental measurements, early results are shown in Fig. 9, where a snapshot of the system working under laboratory conditions can be observed.

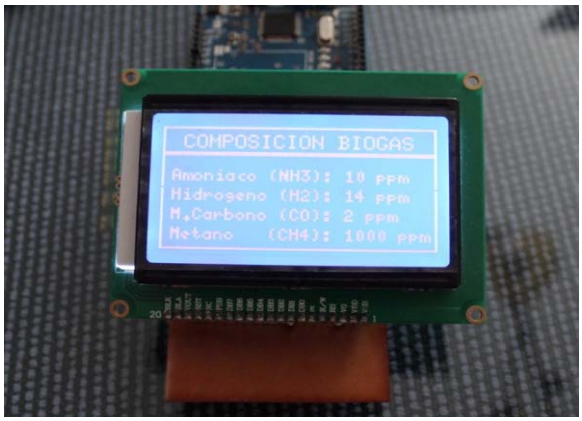


Fig. 9. Prototype working under laboratory conditions.

5. Conclusions

In this paper, the design and development of a cost-effective continuous gas analyzer has been reported. Each of the four sensors chosen for the detection of the biogas composition has been studied and analyzed. Besides, all the circuits necessary for this purpose have being realized. All the circuits that compose the system of measurement and analysis of biogas have been simulated with the software Multisim 14.0, obtaining at all times the corresponding values exposed in the sheets of characteristics of each of them. All the printed circuit boards of the circuits necessary for this project have been implemented with the software Ultiboard 12.0. Currently, the developed meter is in the test phase in order to validate the proposed system. The built prototype proves that a system for biogas sensing is feasible using an open source hardware platform like Arduino. By simply modifying the set of sensors, the presented system can be applied to any other type of gas. Future guidelines include long-term operation assessment and data storage in the form of databases.

References

[1]. D. Deublein, A. Steinhauser, Biogas from Waste and Renewable Resources: An Introduction, *Wiley-VCH*, 2011.

[2]. K. Cacua, A. Amell, L. Olmos, A comparative study of the combustion properties of normal biogas-air mixture and oxygen-enriched biogas-air, *Ingeniería e Investigación*, Vol. 31, Issue 1, 2011, pp. 233-241.

[3]. T. Abbasi, S. A. Abbasi, S. M. Tauseef, Biogas Energy, *Springer*, 2012.

[4]. F. J. Ferrero Martín, M. Valledor Llopis, J. C. Campo Rodríguez, J. R. Blanco González, J. Menéndez Blanco, Low-cost open-source multifunction data acquisition system for accurate measurements. *Measurement*, Vol. 55, 2014, pp. 265–271.
[5]. Arduino web site (https://www.arduino.cc/).
[6]. Raspberry Pi web site (https://www.raspberrypi.org/).
[7]. Intel Edison web site (http://www.intel.com/content/www/us/en/do-it-yourself/edison.html).
[8]. openDAQ web site (http://www.open-daq.com/)
[9]. A. J. Calderón, I. González, M. Calderón, F. Segura, J. M. Andújar, A New, Scalable and Low Cost Multi-Channel Monitoring System for Polymer Electrolyte Fuel Cells, *Sensors*, Vol. 16, Issue 3, 2016, pp. 349-367.
[10]. A. Mejías, M. Reyes, M. A. Márquez, A. J. Calderón, I. González, J. M. Andújar, Easy Handling of Sensors and Actuators Over TCP/IP Networks by Open Source Hardware/Software, *Sensors*, Vol. 17, Issue 94, 2017, pp. 1-23.
[11]. B. D. Lampson, Y. J. Han, A. Khalilian, J. K. Greene, D. C. Degenhardt, J. O. Hallstrom, Development of a portable electronic nose for detection of pests and plant damage, *Computers and Electronics in Agriculture*, Vol. 108, 2014, pp. 87-94.
[12]. T. Järvinen, G. S., Lorite, A. R. Rautio, K. L. Juhász, Á. Kukovecz, Z. Kónya, K. Kordas, G. Toth, Portable cyber-physical system for indoor and outdoor gas sensing, *Sensors and Actuators B: Chemical*, Vol. 252, 2017, pp. 983-990.
[13]. P. Arroyo, J. Lozano, J. I. Suarez, J. L. Herrero, P. Carmona, Wireless Sensor Network for Air Quality Monitoring and Control, *Chemical Engineering Transactions*, Vol. 54, 2016, pp. 217-222.
[14]. J. Carland, M. Umeda, T. Wilkey, A. Oberbeck, J. Cumming, N. Parks, M. Fripp, A. Kuh, D. Garmire, Self-Sustaining Meteorological Wireless Sensor Networks, *Sensors & Transducers*, Vol. 160, Issue 12, December 2013, pp. 118-124.
[15]. F. Ferreira, V. Carvalho, F. Soares, J. Machado, F. Pereira, Vital Signs Monitoring System Using Radio Frequency Communication: A Medical Care Terminal for Beddridden People Support, *Sensors & Transducers*, Vol. 185, Issue 2, February 2015, pp. 93-99.
[16]. A. J. Calderón, I. González, Design and Implementation of a Low Cost System to Determine the Composition of Biogas, in *Proceedings of the 8th International Conference on Sensor Device Technologies and Applications (SENSORDEVICES 2017)*, Roma, Italy, 10-14 September 2017, pp. 76-77.
[17]. FIGARO Engineering inc. web site (http://www.figaro.co.jp/en/product/).
[18]. LPKF CircuitPro Manual (http://www.lpkfusa.com/support/files/manuals/CircuitPro%202.1.x%20How%20To%20Guide-e-2-1.pdf).

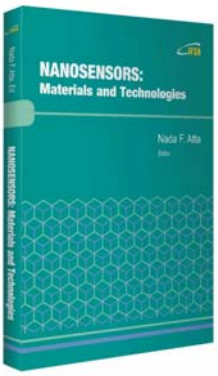
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NANOSENSORS:
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