Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 87 (2014) 520 – 523

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2014, the XXVIII edition of the conference series

Wireless Sensor Node with Ultrasensitive Film Sensors for Emergency Applications

A. Somov[a,*], V. Lebedev[b], A. Baranov[c], E. Laukhina[b,d], V. Laukhin[b,e], R. Passerone[f], C. Rovira[b], J. Veciana[b]

[a]*CREATE-NET, Trento, Italy*
[b]*Institut de Ciencia de Materials de Barcelona (ICMAB-CSIC), Campus UAB, Bellaterra, Spain*
[c]*"MATI"-Russian State Technological University, Moscow, Russia*
[d]*CIBER de Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Spain*
[e]*Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain*
[f]*DISI – University of Trento, Trento, Italy*

Abstract

We present a wireless sensor node with ultrasensitive film sensors for fire detection. The proposed prototype is characterized by temperature and humidity sensors with quick response time, high sensitivity, and low power consumption. Besides, sensors can be deposited directly onboard ensuring a small form factor facilitating their true ubiquitous deployment. The proposed solution can be used for environmental monitoring in difficult to access areas and ensure quick data delivery to a user over the wireless network.

Peer-review under responsibility of the scientific committee of Eurosensors 2014

Keywords: wireless sensor network; sensor node; organic film; ultrasensitive sensor

1. Introduction

Wireless Sensor Networks (WSN) have been already used in a large number of environmental monitoring applications, including fire detection [1]. However, the proposed solutions are either power hungry (up to 200 mW) [2] or insecure, i.e. sensors have poor performance that results in late fire detection [3].

---

* Corresponding author. Tel.: +39-0461-408-400, extension 1406.
E-mail address: asomov@create-net.org

Peer-review under responsibility of the scientific committee of Eurosensors 2014
doi:10.1016/j.proeng.2014.11.538

The goal of this work is to embed a state-of-the-art temperature and humidity film sensors [4, 5] in a wireless sensor node and use it in the emergency applications, e.g. fire detection and unauthorized entry. We first describe the proposed design in terms of sensor node architecture and sensor fabrication. Finally, we evaluate the film sensor performance, wireless link stability with respect to key metrics [10], and estimate the sensor node power consumption.

2. System Design

2.1. Sensor node

The architecture of the sensor, shown in Fig. 1, includes four main blocks: processing, sensing, communication, and power management. The processing unit, based on a ADuC 845 Microprocessor Control Unit (MCU) with a precise 24-bit Analog-to-Digital Converter (ADC), manages the operation of the sensors and of the ETRX3 wireless modem capable of transmitting and receiving data. ETRX3 has a number of self-configuration options which ensure that the WSN can be deployed and debugged in short time. The sensing unit includes the temperature and humidity sensors to detect potential fire or unauthorized entry. The sensors advantages over off-the-shelf components are quick response time and high sensitivity allowing, for instance, to immediately detect a person entry in an office. Power management provides the node with 3 V of supply voltage. As a battery a 3.7 V AA-size Li-ion cell can be used or two alkaline/NiMH 1.5 V each AA-size cells can be applied and wired in series (the first option is preferable due to higher energy density).

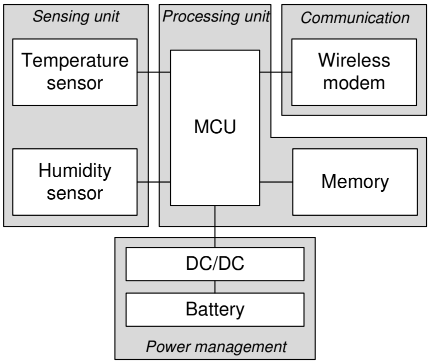

Fig. 1. Sensor node architecture.

Except for the sensors, the electronic components used in this design are off-the-shelf. The novel aspect of the sensor design is the use of “self-metallization” technology that allows the temperature and humidity sensors to be deposited in the empty spaces of the board. Similar techniques have been previously used to deposit other components of the node, such as storage elements [11]. This solution allows the node to have a compact layout without degrading the sensors’ characteristics.

2.2. Ultrasensitive sensors

All-organic flexible sensors based on polycarbonate film/organic molecular conductor bilayer films [4-7] employ the electrical detection principle. As a temperature sensor the polycarbonate/α’-$(BEDT\text{-}TTF)_2I_xBr_{3-x}$ BL film was fabricated [8]; BEDT-TTF=bis(ethylendithio)tetrathiafulvalene. The polycarbonate/$(BEDT\text{-}TTF)_2Br_x(H_2O)_n$ BL film was prepared to be used as a humidity sensor [5]. The sensor fabrication was as follows: first 25 μm thick polycarbonate (PC) films that contain a 2 wt. % of BEDT-TTF, which is precursor for various organic molecular metals, were prepared. The films were cast on glass supports at 130 °C from a 1,2-dichlorobenzene solution of PC and BEDT-TTF. In order to cover the film with the layer of the BEDT-TTF-based conductor we exposed the film surface to the vapors of a dichloromethane solution of either IBr or Br. This redox process induces the formation of the covering polycrystalline layer of either α'-(BEDT-TTF)$_2$I$_x$Br$_{3-x}$ or (BEDT-TTF)$_2$Br$_x$(H$_2$O)$_n$, respectively.

The temperature coefficient of resistance (TCR) for the α'-(BEDT-TTF)$_2$I$_x$Br$_{(3-x)}$ layer was found to be -1.3 %/^{o}C that is in good agreement with early reported data [9]. The TCR was calculated as a relative resistance change per degree. This value is 4 times higher than the TCR of Pt-thermometers (i.e. PT110) commonly used for temperature control. The typical resistance response of the polycarbonate/(BEDT-TTF)$_2$Br$_x$(H$_2$O)$_n$ bilayer film to relative humidity (RH) changes is shown in Fig. 2b; the relative humidity was controlled by a commercial capacitive humidity sensor and indicated digitally in %. Accuracy of the humidity reference sensor is 0,5%, variation in time is ±1,5% RH max. The sensors power consumption is in the range of 2-5 µW that is comparable to the power consumption of the MCU in sleep mode.

3. Experimental Results

In this section we experimentally evaluate the film sensor performance in terms of response time and compare the result with a similar off-the-shelf component. Besides, we evaluate the wireless link that plays an important role in the emergency situations, i.e. safe delivery of alarm messages to the WSN operator.

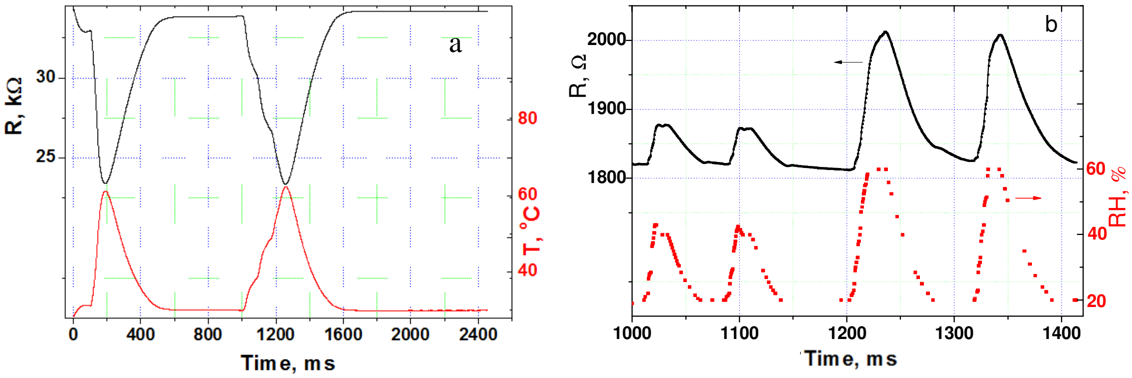

Fig. 2. Sensor performance: (a) resistance of the polycarbonate/α'-(BEDT-TTF)$_2$I$_x$Br$_{3-x}$ BL film (black) and temperature (measured by reference thermometer Pt110) changes (red) *over* time; (b) resistance of the polycarbonate/(BEDT-TTF)$_2$Br$_x$(H$_2$O)$_n$ BL film (black) and humidity (measured by commercial capacitive humidity sensor) changes (red) *over* time

Fig. 2a clearly shows that the electrical response of the polycarbonate/α'-(BEDT-TTF)$_2$I$_x$Br$_{3-x}$ BL film to temperature changes is reversible and a well reproducible signal. Moreover, this response is as fast as the response of thermometer Pt110. As shown in Fig. 2b the electrical response of the polycarbonate/(BEDT-TTF)$_2$Br$_x$(H$_2$O)$_n$ bilayer to RH changes is very reproducible and strongly depends on the value of RH. The resistance of this sensing BL film also demonstrates quick response time. The electrical response of the polycarbonate/(BEDT-TTF)$_2$Br$_x$(H$_2$O)$_n$ bilayer increased by 6%, when RH changed from 20 to 65% that is in good agreement with previously reported data [5]. Here it should be noted that this BL film is three times more sensitive to RH changes in comparison with the BL film-based sensor reported by G. Saito et al. [7].

Table 1 reports the maximum operating distance of the wireless sensor node. It can transmit messages as far as 350 m. However, low Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI) for this distance result in poor Packet Delivery Rate (PDR) that is unacceptable for emergency applications. The experimental results show that safe data transmission can be realized up to 100 m in direct line of site outdoor conditions.

Table 2 shows an experimental estimation of the average power consumption of the node. The sensors consume negligible power. The most power hungry component is the wireless transmitter, consuming less in receive mode (RX) and more in transmit mode (TX). In order to reduce the power consumption we perform data transmission only in the case of emergency or for service needs. Most of the time the MCU and radio are in sleep mode.

Table 1. Average performance of wireless channel in direct line-of-site conditions between a sensor node and a gateway.

Distance, m	RSSI, dBm	LQI	PDR, %	TX level, dBm
3	-40	FF(255)	100	3
6	-47	FF(255)	100	
12	-57	FF(255)	100	
25	-65	FF(255)	100	8
50	-66	FD(253)	100	
100	-73	EF(239)	100	
150	-73	ED(237)	96	
200	-75	DB(219)	96	
300	-76	D2(210)	95	
350	-83	B8(184)	35	

Table 2. Average power consumption of sensor node and comparative study on relevant sensors.

Device	Power consumption at 3 V, mW	
	Active mode	Sleep mode
Film sensor*	0.005	0
ETRX3 Radio (TX)*	93 at 3 dBm	0.003
ETRX3 Radio (RX)*	78	0.003
ADuC845 MCU*	15	0.06
808H5V5, Sencera humidity sensor	1.25	0
SGS-2140, Delta-S CO & H2 (fire)	215	0

*- components used in this work.

The experimental results demonstrate the sensor node high performance (Fig. 2) in terms of response time, long-term sensing without drift, wireless communication (Table 1), average power consumption (Table 2) and open up a wide opportunity for emergency applications.

Acknowledgements

The authors acknowledge the Russian Federal Program “Development of Electronic Components and Radio Electronics” Grant No. 14.427.11.0007. This work was also supported by the Spanish Direcci´on General de Investigacion (DGI) (project POMAs, CTQ2010-19501/BQU), the Generalitat de Catalunya (2009SGR00516). E.L. thanks CIBER-BBN, an initiative funded by the VI National R&D&i Plan 2008-2011, Iniciativa Ingenio 2010, Consolider Program, CIBER Actions and financed by the Instituto de Salud Carlos III with assistance from the European Regional Development Fund; V. Lebedev acknowledges a grant FIDGR from the Generalitat de Catalunya.

References

[1] D. Puccinelli, M. Haenggi, Wireless sensor networks: applications and challenges of ubiquitous sensing, IEEE Circuits and Systems Magazine 5 (2005) 19-31.

[2] A. Somov, D. Spirjakin, M. Ivanov, I. Khromushin, R. Passerone, A. Baranov, A. Savkin, Combustible gases and early fire detection: an autonomous system for wireless sensor networks. In: Proceeding of e-Energy, Passau, Germany, 2010, p. 85-93.

[3] D. M. Doolin, N. Sitar, Wireless sensors for wildfire monitoring. In: Proceedings of Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems, San Diego, CA, USA, 5765 (2005).

[4] E. Laukhina, M. Mas-Torrent, C. Rovira, J. Veciana, V. Laukhin, Organic sensor device for e.g. molecular electronics, has layer of organic material having conductive salt or complex including molecule and dopant, and base substrate provided in close contact with layer of organic material, Patent: WO2008059095-A1; ES2299392-A1, 2008.

[5] V. Lebedev E. Laukhina, C. Rovira, V. Laukhin and J. Veciana, All-Organic Humidity Sensing Films with Electrical Detection Principle Suitable to Biomedical Applications, Procedia Engineering 47 (2012) 603 – 606.

[6] E. Laukhina, R. Pfattner, L. R. Ferreras, S. Galli, M. Mas-Torrent, N. Masciocchi, V. Laukhin, C. Rovira, and J. Veciana, Ultrasensitive piezoresistive all-organic flexible thin films, Adv. Mater., 22 (2010) 977-991.

[7] T. Haneda, A. Tracz, G. Saito, H. Yamochi, Continuous and Discontinuous Water Release/Intake of (BEDO-TTF)$_2$Br(H$_2$O)$_3$ Micro Crystals Embedded in Polymer Film*,* J. Mater. Chem., 21 (2011) 1621-1626**.**

[8] E. Laukhina, V. Tkacheva, S. Khasanov, L. Zorina, J. Gomez-Segura, A. Perezdel Pino, J. Veciana, V. Laukhin, C. Rovira, Linked Crystallites in the Conducting Topmost Layer of Polymer Bilayer Films Controlled by Temperature: From Micro- to Nanocrystallites, ChemPhysChem, 7 (2006) 920 – 923.

[9] E. Laukhina,V. Lebedev, V. Laukhin, G. Oncins, R. Pfattner, C. Rovira, J. Veciana, Lightweight Biocompatible Physical Sensors: Polymeric Films “Self-metallized” with Organic Molecular Conductors. In: Proceedings of Transducers’11, Beijing, China, 2011 p. 1978-1081.

[10] A. Somov, A. Baranov, D. Spirjakin, A. Spirjakin, V. Sleptsov, R. Passerone, Deployment and evaluation of a wireless sensor network for methane leak detection. J. Sens. Actuators A, Phys. 202 (2013) 217-225.

[11] A. Somov, C. C. Ho, R. Passerone, J. W. Evans, and P. K. Wright, Towards extending sensor node lifetime with printed supercapacitors. In: Proceedings of the European Conference on Wireless Sensor Networks, Trento, Italy, 2012, p. 212-227.