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Enhancing lifetime of WSN for natural gas leakages detection

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ABSTRACT

Monitoring dangerous aerosols in indoor environments is essential to prevent illnesses and to provide safety to inhabitants. Natural gas in particular is an explosive chemical widely adopted in homes. Failures in its distribution network can be very harmful. We propose a WGSN to monitor indoor environments and to promptly report alarms in case of failures and leakages. It employs low-cost off-the-shelf devices like chemoresistive MOX sensors and state-of-the-art wireless electronic boards. We exploited the transient response of the sensing element to reduce by 20 × the power required to assess the indoor air quality. Performance evaluation has been conducted using gas bench and demonstrates the effectiveness of our approach. Our system requires very few mW of power to work and enhances the battery autonomy of about 300% with respect to nominal use of the sensor, with two standard AA batteries.

1. Introduction

Indoor air quality (IAQ) assessment will be mandatory to respect environmental regulations and, primarily, to guarantee safe living conditions for people. More than 150 accidents are reported every year that are related with natural gas leakages, only in Italy. Distributed monitoring systems should be affordable for everyone in order to substantially reduce injuries and dramatic events.

Smart homes are intended as pervasive environments where networks of wireless interconnected electronic devices will provide services and information to simplify and assist people's life. We cannot afford bulky and expensive instruments to be installed and distributed in every home. Our goal is to realize a reliable Wireless Gas Sensor Network with commercial off-the-shelf available electronic components. Mandatory design features are the long lifetime with no maintenance nor refill of chemicals reagents, very small dimensions to fit in any kind of place and, of course, prompt response in the case of harmful environmental conditions.

Research in WSN is going on from the last twenty years but in the field of volatile chemical sensing many improvements are required to achieve a reliable system with at least two years of autonomy. Our system is based on chemoresistive gas sensors (MOX) that are very low cost and can last for years without human intervention. The main problem of this sensing technology is the huge amount of power required to perform a measurement. Table 1 compares the requirements, in terms of current, of commercial electronics devices commonly used in sensor networks with MOX sensors. The consumption of MOX is higher even than that of radio-transceivers, normally referred as the most power hungry devices in WSN.

In this scenario, we propose and demonstrate a technique based on the MOX's transient response characterization in the frequency domain. The target of this approach is twofold; on one side we drastically reduce the power consumption by 20 ×, switching-on the device for very short time, fixing the repetition interval of the measurement in a duty-cycled fashion. On the other side, using 1 min environmental assessment frequency, we achieve a really prompt monitoring system that is mandatory given the dangerousness of the natural gas. To the best of our knowledge, frequency based analysis of the MOXs' transient response was never investigated in WSN applications for indoor air quality assessment, nor in ultra low power systems and neither in battery operated devices which need to maximize their lifetime. Our results shows that reducing substantially the power needed to sense the environment and to assess the gas concentration is possible. In the same time, we discuss also the limitations of available standards for wireless communication protocols based on IEEE 802.15.4.

The novelty of the proposed approach is in the reduced amount of energy required by the sensing and evaluating embedded system to assess the air quality and eventually react to leakages. We present results obtained with real WSN deployment in real homes, in addition to standard characterization using lab facilities and controlled environments that are rarely presented in the literature because of the difficulty, the time and money efforts required to deploy gas targeted systems.

This paper is organized as follows: a review of the state-of-the-art in this field is presented in Section 2, while Section 3 describes the problem of monitoring volatile chemical substance with low-power

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Table 1
Comparison of power consumption of devices commonly used in sensor node design.

Device	Manufacturer	Consumption
Gas sensors		
MICS-5121	e2v	32 mA
TGS2610	Figaro	56 mA
AS-MLK	Applied sensors	15 mA
Radio transceivers		
JN5148-001	NXP	TX: 15 mA RX: 17.5 mA
CC2500	Texas Instruments	TX: 21.2 mA RX:13.3 mA
Microcontrollers		
JN5148-001	NXP	Active mode: 8 mA at 3 V/32 MHz and deep sleep mode: 1.3 μA
MSP430F247	Texas Instruments	Active mode: 321 μA at 3 V/1 Mhz and low power mode: 1 μA at 3 V/32.768 KHz

electronic systems and the setup used in our research. Section 4 presents the proposed strategy to extend the lifetime of Wireless Gas Sensor Networks. In Sections 5 and 6, we present the results of the sensor's characterization evaluated in a gas bench and the resulting lifetime improvements in real scenario. Section 7 concludes this work with final remarks.

2. Related works

In the field of WSN for environmental monitoring most of the efforts are targeted to monitor pollutants according to current regulations. In outdoor scenario harvesting techniques increase the lifetime of monitoring nodes and photovoltaic panels can provide enough power to sustain nodes (and backup batteries) almost forever [1,2]. Similar solutions are not useful indoor where renewable sources can scavenge only few tens of mW, not enough to sustain wireless nodes with power hungry devices like chemoresistive sensors.

Commercial devices like chemoresistive gas sensors are rarely used when the lifetime of the monitoring network is the target goal. Innovative devices were developed (for example in [3]) to achieve very low consumption to the detriment of the costs . Even if targeted to indoor monitoring, in this paper the size of the device were not considered a limitation hence very big batteries were adopted as supply. Adaptive sampling [4–6] and complex processing techniques [7] have been proposed to reduce the power required to switch on the sensing element, but also the network overhead [8]. Strategies that require complex and dedicated hardware increase the costs and are not suitable with low power microcontrollers (MCU).

Most of the works developed during the last ten years in the field of volatile chemical sensing do not consider at all consumption and lifetime in the design [9]. Those were mainly focused on increasing the sensitivity and the capability to discriminate between target chemicals compounds. In the same work authors underline the importance and the need of efforts to extend the autonomy of battery powered sensing instruments to make gas sensor widely available in different scenario, which is actually our goal.

3. Aerosol measurement

The measurement of gas concentration in air can be performed exploiting several chemical principles and it results in different sensing technologies available in the market. The most suitable one for employment in portable and battery-powered electronics is the chemoresistive family. This has advantages with respect to the other sensing technologies like chemo-optical and electrochemical.

Chemoresistive sensors consist of several stacked layers of different materials. They are built on a silicon substrate in CMOS technology which results very cheap for industrial production. MOXs (Metal OXide semiconductor sensors) exploit a reversible chemical reaction that occurs in the sensitive layer, triggered by the heat. The heat is provided by an inner metal layer which requires high power to heat up in few milliseconds and maintain the whole structure around 400 °C. The power provided to the heater must be kept constant during the whole measurement phase. In duty-cycled applications, where the sensor is periodically switched on, a minimum interval of 5 s is required to reach a stable response [7].

The sensitive layer consists of semiconductive material which changes its conductivity according to the amount of particles that are deposited on it. The volatile analyte in the surrounding environment reaches the sensitive layer passing through a filter which prevents extraneous substances (e.g. dust) to enter the device [10]. Main issues to MOXs' sensitivity are the filter that let almost any kind of volatile to deposit on the sensitive layer; and the low selectivity of the alloy used as sensitive layer. This layer reacts to family of chemical compounds and the response depends also on environmental conditions. Temperature and humidity strongly affect sensor's response since particle mobility (temperature) and the presence of water (humidity) interact with target chemicals in air and during the reversible reaction. The output signal of MOXs depends on all the above considerations which must be taken into account in the definition of the characteristic response.

Despite no negligible power consumption is required to perform a measurement, MOXs have very low price and they do not need maintenance nor refills of reagents during their lifetime. These are great advantages for wireless sensor networks and affordable for large deployments.

In this work, the AS-MLK sensor from Applied Sensors has been used [11]. This sensor is targeted to continuous natural gas monitoring and it is normally used in this kind of applications (like in commercial smoke detectors). We mounted it on a state-of-the-art electronic board depicted in Fig. 1 – left. The W24TH board [12], from Wispes, hosts a very powerful microcontroller in which the main features are the 32-bit architecture, the integrated radio module and antenna, IEEE 802.15.4 compliant, a number of integrated sensors (temperature, light, humidity, accelerometer and dock for MOXs) and expansion connector for external analog/digital devices.

We used this setup to evaluate the proposed strategies both with gas bench and in real environments. The gas bench setup provides separated line for volatile chemicals each monitored by a mass flow detector. Analytes, stored in tanks, are mixed together automatically by a software that controls hydraulic intake valves and mass flow detectors in feedback configuration.

4. Proposed strategy

The sensor characterization has been performed by running several experiments in the controlled sealed chamber. We tested different analyte concentrations (from very low as 0.1% to medium like 1%) to achieve a reliable sensor response characterization. As previously introduced, to obtain a stable response in duty-cycled applications MOXs requires more than 5 s. To reduce the power consumption substantially, the active time must be reduced. We observed, by empirical analysis, that using fixed and short time