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Investigation of heating profiles and optimization of power consumption of gas sensors for wireless sensor networks

Denis Spirjakin [a], Alexander M. Baranov [a], Andrey Somov [b,*], Vladimir Sleptsov [a]

[a] Moscow Aviation Institute (National Research University), 125993, Moscow, Russia
[b] University of Exeter, College of Engineering, Mathematics and Physical Sciences, EX4 4QF Exeter, UK

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ABSTRACT

Monitoring of hazardous and combustible gases at industrial premises and in the living apartments has been a topic of top priority for a number of decades. Within the last decade a great many of solutions have been proposed including the one relying on the Wireless Sensor Network (WSN) paradigm. Being an autonomous monitoring system, it is essential to guarantee a long lifetime of gas WSN. In this work, we are investigating and implementing a number of heating profiles for catalytic and semiconductor sensors used on board of the wireless sensor nodes to reduce their power consumption. After analyzing the pros and cons of these profiles, we propose the heating profile based on the Pulse Width Modulation (PWM) and the multi stage heating profile. Experimental results demonstrate that the average current consumption of the gas sensor node can be reduced up to 0.76 mA and its power consumption up to 2.54 mW thereby ensuring the autonomous operation of the sensing device for more than one year.

1. Introduction

A Wireless Sensor Network (WSN) is a collection of tiny sensing devices, sensor nodes, with the wireless communication capability. Most of the time sensor nodes spend in sleep mode to ensure long-term operation of WSN. Depending on duty cycle the sensor nodes wake up from time to time, measure physical phenomena and send the data to a user over the WSN. Due to the WSN flexibility they have been employed in a high number of monitoring and control applications, e.g. environmental [1] and wild life monitoring [2], road tunnel [3] and building structural health monitoring [4], gas leak [5] and fire detection [6].

Most of the monitoring applications require low power sensors, e.g. temperature, light, accelerometer, on board of sensor nodes. The applications aiming at the detection of hazardous or combustible gases in the environment rely on inherently power hungry catalytic or semiconductor gas sensors which meet the industrial standards requirements in terms of sensor response time [7,8]. Safety standards require annual calibration of gas sensors which implies one year of autonomous operation of gas WSN.

A high number of power consumption optimization techniques for gas WSN have been proposed recently [9,24]. For example, context aware sensing [10] adjusts the gas sensor node duty cycle with respect to people presence in the area, a design space exploration framework [11] ensures energy efficient WSN nodes design, improved thermal insulation packaging [12] prevents heat dissipation during the measurement procedure and energy harvesting technology which helps to replenish the energy storage of gas sensor nodes [13]. Even though these approaches contribute towards the power consumption reduction of gas sensor nodes, they are not truly helpful: a lion share of power during the operation of sensor nodes is consumed by catalytic/semiconductor gas sensors in contrast with typical monitoring applications where a wireless transceiver is the most power hungry component of the sensor node [14].

Novelty and contribution of this work is implementation and investigation of sensing circuits and associated heating profiles for gas sensors nodes as well as proposing a heating profile based on Pulse Width Modulation (PWM) and multistage heating profile. The goal of this work is to estimate the power consumption of various heating solutions and discuss their pros and cons.

This paper is organized as follows: Section 2 introduces gas sensing platform for investigation of various heating profiles, in Section 3 we implement and discuss these heating profiles with a special focus on their power consumption, in Section 4 we present the heating profile based on PWM and multistage heating. Finally, we provide conclusions in Section 5.

* Corresponding author.
E-mail address: a.somov@exeter.ac.uk (A. Somov).

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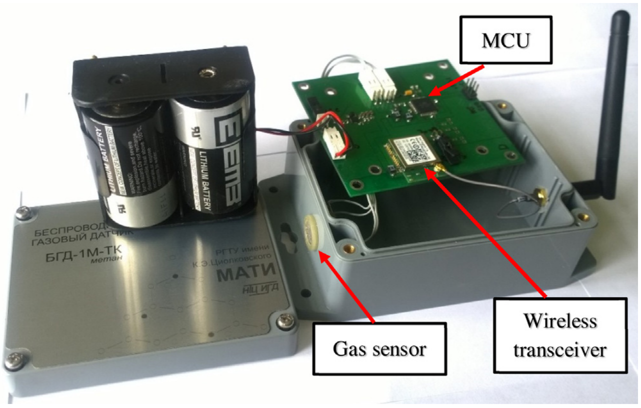

Fig. 1. Wireless combustible gas sensor node prototype.

2. Gas sensing platform

Power consumption of catalytic and semiconductor gas sensors was reduced from hundreds of mW to tens of mW [9,15,16] within a couple of decades. At the same time, commercially available sensors [17–19] are still power hungry electronic components that prevents their application on board of autonomous sensing devices.

In this work, we use the catalytic sensor DTK fabricated by NTC IGD, Russia. DTK sensor height is 9.5 mm, diameter is 9 mm and power consumption is around 190 mW in continuous measurement mode. Its power consumption is much lower comparing to other commercial samples [17–19] and is achieved by applying a heater implemented as 10 μm platinum micro wire in glass insulation (2 μm). The sensor package includes two sensing elements: an active and reference (or passive) one. The active sensing element has a platinum micro wire covered by porous gamma alumina oxide material that is used as catalyst support for catalytically active metals (mixture of Pd and Pt). In order to impregnate the catalyst support by the catalytic metal, salts of palladium chloride ($PdCl_2$) and platinum acid (H_2PtCl_6) are used. After annealing at 500 °C, noble metal clusters are formed in the catalyst support. To conduct the measurements with the Wheatstone sensing circuit both sensing elements are involved in sensing. For the sensing circuits based on one sensor (see Sections 3.2 and 3.3) only active sensing element performs sensing.

Circuits for gases detection with catalytic sensors are commonly based on the Wheatstone bridge, which includes two resistors and two sensing elements, as specified earlier. Most of the power goes into the sensor heating process (about 450 °C for methane detection), required to perform the measurement. The power consumption of the Wheatstone circuit (around 150 mW) is high enough that makes its application in the WSNs unlikely. However, by optimizing the gas sensor and sensor node operation the total power consumption can be significantly reduced.

The active sensing element is used to conduct the measurement. The reference sensing element, which is identical to the active one but not covered with the catalyst and therefore insensitive to the gas concentration, is used to compensate for environmental factors such as temperature and humidity. The resistance of the active and reference sensing elements is about 12 ohm each under normal condition. This measurement approach is highly reliable in terms of quality of measurements. As noticed earlier, the optimization of its power consumption is required.

In this work, we investigate a number of options on decreasing the power consumption of wireless gas sensor node for methane detection.

Fig. 2a presents a block diagram of the wireless gas sensor node. The sensor node is built around the AtXmega32A4 Microcontroller Unit (MCU) and use an ETRX3 wireless modem. The selection of the MCU was mainly driven by the following requirements: low power consumption, on-chip temperature sensor, and precise Analogue-to Digital Converters (ADC) and Digital-to-Analogue Converters (DAC) integrated in MCU.

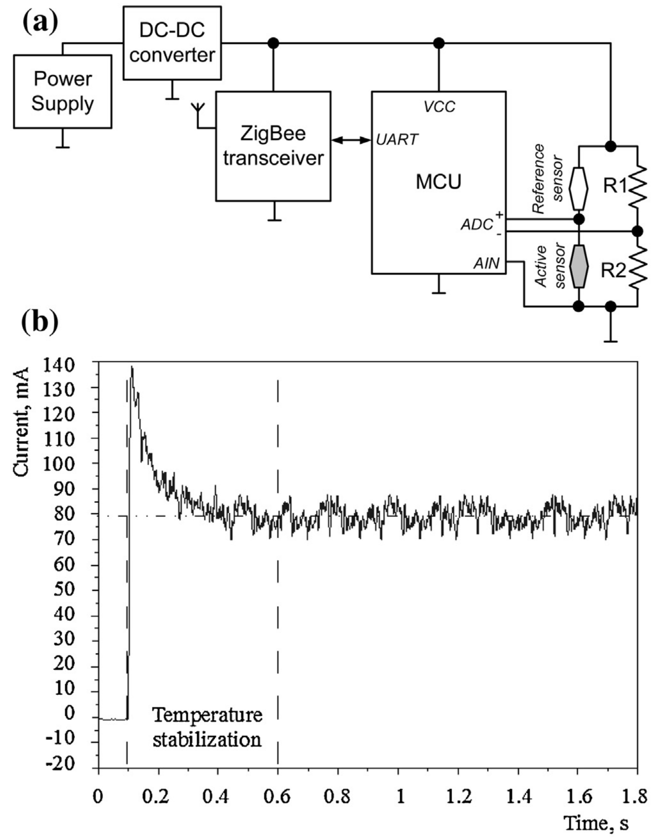

Fig. 2. (a) Block diagram of the wireless combustible gas sensor node in continuous mode of operation and (b) its current consumption.

The wireless modem supports IEEE 802.15.4 standard (ZigBee specification) and transmits in unlicensed 2.4 GHz ISM band. The modem has an integrated chip antenna used in this design (transmitting distance is up to 25 m) and a connector for an external antenna to enable a boost mode allowing data transmission for up to 350 m. Besides that, the modem has a number of self-x features enabling, for instance, WSN self-configuration and self-diagnostics which significantly reduce WSN debugging and deployment time.

Two batteries of D type with voltage 3.6 V are used in the wireless sensor node. Capacity of a single cell lithium battery of D type is typically 15000 mAh. Its voltage is 3.6 V. Since there are 8760 h a year, the average discharge current for one year sensor node lifetime is no more than 2 mA. Power management is performed by a DC-DC converter TPS63060 which generates stable output voltage from 2.5 V to 12 (the maximum value is 7.2 V for two D-type batteries) on its input. The sensor node prototype is shown in Fig. 1.

Comparative study on power consumption of electronic components used in the gas wireless sensor node design is shown in Table 1. The data for sensor is obtained experimentally other ones are taken from the technical specification of the components.

3. Investigation of heating profiles

In this section we investigate the heating profiles for catalytic sensors. This study is carried out by implementing the sensing circuits and associated heating profiles using the sensor node platform presented in Section 2. The platform experienced some