Continuous Remote Ammonia Monitoring by Air Quality Measurement and Communication System

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Abstract. The current paper represents the portable system for monitoring of air quality by detecting the concentrations of an ammonia gas based on compact MOS sensor. The presence of the ammonia gas in the outdoor or indoor air is very important for the human health and safety because it may be dangerous in high concentrations. The continuous monitoring of the This portable system is designed to meet the requirements of the health protection not only in the indoor environments but also in the urban, industrial and rural locations by continuous measurement and transmission of the data to the remote server for real-time analysis of the working space air. The paper discusses the calibration and test of the metal-oxide sensors due to the very wide range of the initial sensitive layer resistance and calculation of the ammonia gas concentration in the air.

Keywords: Ammonia measurement · Air quality measurement system

1 Introduction

Atmospheric ammonia (NH_3) has long been recognized as the key important air pollutant contributing to the human health [1]. It originates from both natural and anthropogenic sources, with the main source being agriculture, e.g. manures, slurries and fertilizer application. Also Ammonia (NH3) is a colorless gas with a characteristic pungent odor, which is a common precursor to fine particulate matter (PM2.5), making it an important consideration for PM-related health effects [2]. Primarily wet tissue (i.e. eyes, nose, and throat) irritation and damage are recognized as corneal and skin burns/blistering, intraocular pressure (glaucoma), coughing, pulmonary and laryngeal edema, chest pains, pinky/frothy sputum, etc. and it can be dangerous because there is no antidote for ammonia poisoning. Therefore the continuous ammonia monitoring also is important for security reasons and human health risks. OSHA has set an 8-h exposure limit of 25 ppm (25,000 ppb) and a 15 min exposure limit of 35 ppm (35,000 ppb) for ammonia in the workplace. The research arm of OSHA has recommended the ammonia level in a work room be no more than 50 ppm (50,000 ppb) per 5 min of exposure [3].

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The mobile measurement of the air quality and gas concentrations is a very actual problem due to the great human mobility, pollution motion and the absence of measurement stations in most places especially for the closed spaces. The measurement data are sent via GSM/GPRS modem to the remote server but also may be transmitted to the located nearby devices via Bluetooth connection. The metal-oxide (MOX) sensors are widely used to measure the concentrations of the air pollutant gases. Their main advantages are recognized as low cost (around 10–15€ per sensor), long lifetime (>5 years), good sensitivity from mg/m^3 to μg/m^3, but also have some drawbacks - results are affected by temperature and humidity variations, long response time (5–50 min), output depends as well on history of past inputs and instability can be observed. Also in order to increase sensitivity the sensing layer needs to be heated to temperatures of at least 250 °C. Due to their small form factor, metal-oxide sensors are integrated in Internet of Things (IoT) devices and mobile platforms, but these sensors suffer from low selectivity and poor long-term stability. For example MICS-4514 sensor tests [4] shows good coefficient of determination values (0.76–0.78) with respect to reference measurements but the same models performed poorly during the 4.5 months validation phase with coefficient of determination values being less than 0.1.

The current paper discusses the short-term tests and calibration of the similar MOX sensors due to the very wide range of the initial sensitive layer resistance and calculation of the ammonia air concentrations.

2 System Description

Ambient air quality monitoring equipment includes gas detectors and portable and personal instruments that monitor ambient air in the workplace to help detect the presence of toxic vapors and gases. It is based on compact MOS sensor MiCS-6814 [5], which combines three independent sensing elements for ammonia, carbon oxide and nitrogen oxides on one package. Each sensor includes a heating circuit and sensing element (Fig. 1). The detecting layer changes its resistance according to the pollutant concentration. The sensing resistance in air varies from 10 to 1500 kΩ for the NH_3 sensor, therefore the sensor requires a calibration to measure the real concentrations.

The measurement and the communication device is described in our previous work [6] and consists of GPS receiver, GSM/GPRS modem and Bluetooth transceiver, power supply unit and user indication LEDs. The system microcontroller is based on PIC16F family (PIC16F1825) and has built-in I^{2}C interface as a part of Master synchronous serial port (MSSP) module and EUSART with an autobaud interface, which is connected to the GSM/GPRS modem with RTS/CTS hardware flow control. To meet the portable device requirements the measurement and the communication part may be powered by external power source via micro USB connector or by built-in Li-Ion battery with 900 or 1800 mAh capacity. As the external power source is connected the battery is charged by default. The charging current is set via an external resistor and its maximum value is equal to 500 mA. The power management chip employ a constant-current/constant-voltage charge algorithm and charge termination. Also the GPS receiver LDO chip has an enable input which is controlled via AT command by GSM/GPRS modem to switch off the GPS receiver to save power if GPS module is not needed or the device is stationary.

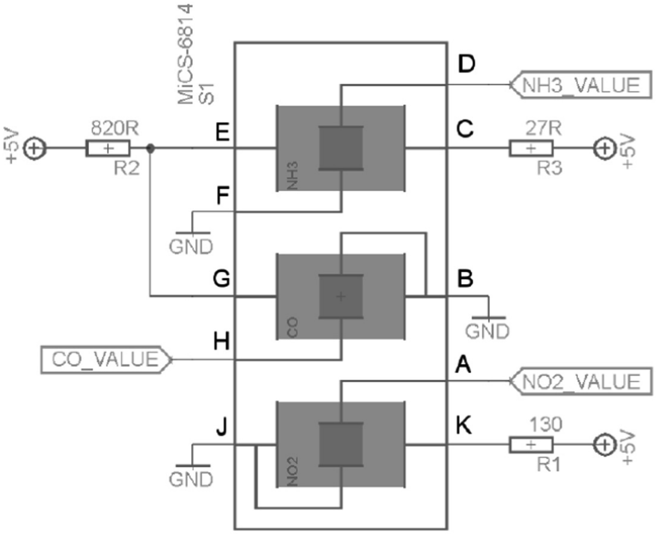

Fig. 1. Gas sensor [4]

3 System Calibration

Before the ammonia monitoring we have to calibrate the sensor data due to the high range fluctuation of the sensor resistance in air. The calibration is made in the environment of a pure nitrogen at normal temperature by measuring the sensing resistance R_0. When the sensor is exposed to the air the resistance is change to Rs value which corresponded to the gas concentration according to the Rs/R_0 to Concentration graphics (Fig. 2) [5].

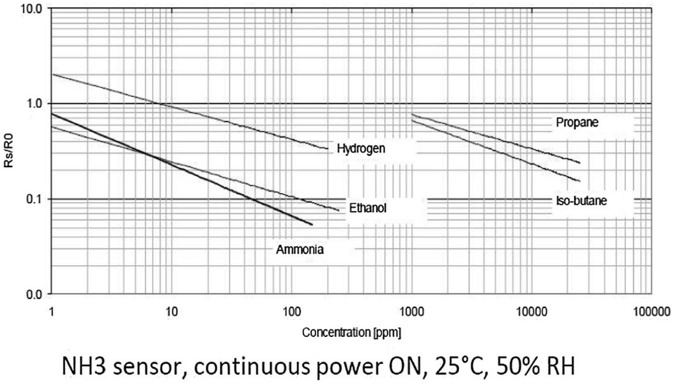

Fig. 2. Ratio Rs/R_0 as a function of concentration [5]

The sensing resistance Rs is converted to voltage using resistor divider and then the built-in in the microcontroller 10-bit ADC converts this voltage to a digital word (Fig. 3). The second resistor in the divider is chosen to be equal to $R_1 = R_0$ to guarantee the maximum amplitude response of the ammonia gas to the sensing element. The sensing resistance may be affected by the temperature, humidity and time [6], so the temperature also have to be measured and the calibration procedure have to be accomplished if an optimum accuracy is required.

According to the manufacturer curves [7], the gas concentration is calculated by the equation $lgY = a*lgX + b$, where X and Y denote the gas concentration in ppm and Rs/R_0 value respectively and a and b are constants. If we denote adc as the ADC digital word (resolution $N = 10$ bit) and $Uref$ as the ADC reference voltage, than the concentration Y_1 may be obtained from the data from the other concentration Y_0 which may be the calibration concentration according to the following calculations:

1/Calculate divider voltage $Uadc$ from the power supply voltage VCC and resistance of the sensing element and the second divider resistance R1 (Fig. 3) according to the manufacturer recommendations:

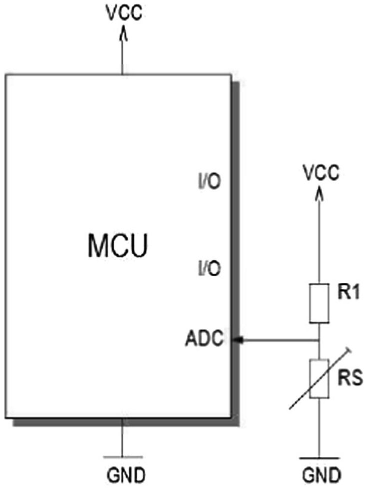

Fig. 3. MiCS-6814 sensor measurement circuit

$$Uadc = VCC.\frac{Rs}{Rs + R1} \tag{1}$$

$$Uadc = Uref.\frac{adc}{2^N} \tag{2}$$

Therefore:

$$\frac{Rs+R1}{Rs}=\frac{VCC}{Uref}\cdot\frac{2^N}{adc} \tag{3}$$

$$\frac{R1}{R0}=\left(\frac{Rs}{R0}\right)\cdot\left(\frac{VCC}{Uref}\cdot\frac{2^N}{adc}-1\right)=const \tag{4}$$

2/According to Eq. (4) at two different concentrations Y_0 and Y_1:

$$\left(\frac{Rs}{R0}\right)_0\cdot\left(\frac{VCC}{Uref}\cdot\frac{2^N}{adc_0}-1\right)=\left(\frac{Rs}{R0}\right)_1\cdot\left(\frac{VCC}{Uref}\cdot\frac{2^N}{adc_1}-1\right) \tag{5}$$

Therefore:

$$\frac{\left(\frac{Rs}{R0}\right)_1}{\left(\frac{Rs}{R0}\right)_0}=\frac{K_0}{K_1} \tag{6}$$

where

$$K=\left(\frac{VCC}{Uref}\cdot\frac{2^N}{adc}-1\right) \tag{7}$$

3/From the calibration equation

$$logY=alog\left(\frac{Rs}{R0}\right)+b$$

follows that $log\frac{Y_1}{Y_0}=alog\frac{\left(\frac{Rs}{R0}\right)_1}{\left(\frac{Rs}{R0}\right)_0}=alog\frac{K_0}{K_1}$

Respectively

$$Y_1=Y_0\left(\frac{K_0}{K_1}\right)^a \tag{8}$$

We establish the following constants for the dependence of the Rs/R_0 value towards the concentration of NH_3: a = −0,50084; b = −0,1728.

4 Results

The measurements are accomplished in the indoor situation such as office room. Two ammonia sensors are situated at the different places in the room and the test duration is over 36 h. The data are sent to the remote server every 30 s and are written in the MySQL database via Bluetooth or GPRS connection. Furthermore the data are extracted in the CSV file and analyzed. The ammonia concentration and the room temperature are shown at Figs. 4 and 5 respectively. The results show very good data correlations especially after the initial start-up period. The stable data are obtained after the 20 min power-up period. The measurement data also may be more accurate if the sensor outputs are buffered due to the sensitive layer resistance which varies from 10 to 1500 kΩ while the PIC ADC input recommendations requires maximum sensor output resistance of 1 kΩ.

The experimental results show that the ammonia concentration in the indoor environment sometimes may be continuously measured and analyzed to minimize the human health risks due to the ammonia exposure. The both sensors shown similar ammonia concentrations which are much below the dangerous levels but may reach the levels of 3–4 ppm for a time period of 1 h or more.

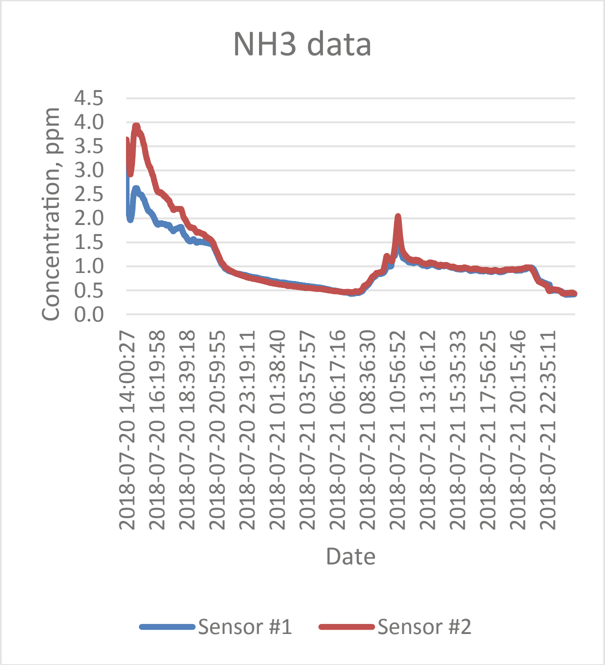

Fig. 4. Ammonia concentration as a function of time

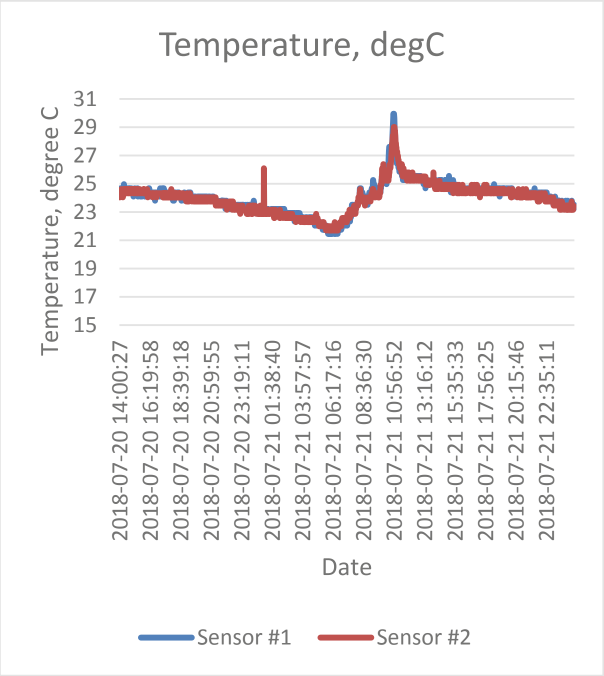

Fig. 5. Temperature as a function of time

5 Conclusion

The current paper discusses the calibration and test of metal-oxide (MOX) sensors for ammonia gas concentration calculation. According to the calibration coefficients we obtain the gas concentration Eq. (8) which is an exponential function of the system parameters.

The long-term continuous measurements of NH_3 at different locations (i.e. urban, industrial and rural) is very important to the air quality. Such type of portable measurement and communication systems may be used not only for monitoring of the working air quality but also to alarm for high ammonia levels in the industry, transport, etc. The measured data are transmitted to the remote server and the ammonia concentration geolocation may be very useful for the people which may have not such device but may be alarmed for the hazard levels of the ammonia gas by the installed application in the smartphones. This application may read the GPS position of the human and check in the server data the current ammonia level to prevent health risks.

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