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MULTI-SENSOR GAS-SENSING HEAD FOR AIR QUALITY EVALUATION

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Abstract

A prototype of a multi-gas-sensing head is developed for early detection of conventional (criteria) pollutant gases and their concentration. Its main purpose is air quality monitoring in office or residential buildings, industrial facilities and for outdoor applications. This may be used from the respective authorities to take due measures preventing gas spreading and most importantly person's health from the impact of the target gas.

The prototype is designed to give access to the signals from the sensor circuits via a single USB port. Two LabVIEW VIs are developed: one that detects, observes and transforms these signals in a suitable manner and a separate application to visualize them with a human readable value.

Keywords: air quality monitoring; multi-gas-sensing head; signal processing.

INTRODUCTION

Air pollution is a global threat leading to negative effect on human health and ecosystems, climate change and economic impacts. Emissions and concentrations have increased in many areas worldwide. Air quality affects public health. The effect of air pollution ranges from difficulty in breathing, coughing, aggravation of asthma and emphysema. Polluted air can also impair visibility. Children exposed to air pollution have an elevated risk of developing chronic respiratory problems such as asthma. Air pollution has several important environmental impacts and may directly affect vegetation and fauna, as well as the quality of water and soil and the ecosystem services that they support. The effects of air pollution on health, crop and forest yields, ecosystems, the climate and the built environment also entail considerable market and non-market costs. The market costs of air pollution include reduced labour productivity, additional health expenditure, and crop and forest yield losses. [1, 2]

In order to prevent human health and to guide national and local authorities in their risk management decisions WHO (World Health Organization) publishes air quality guidelines (WHO, 2000, 2006a).

In Europe, air quality in many areas remains poor, despite eductions in emissions and ambient concentrations[3] trying to meet the air quality standards established in the two Ambient Air Quality Directives presently in force (EU, 2004, 2008).

Air quality monitoring stations are traditionally used for measuring the concentrations of certain pollutants of interest. There are 2 types of monitoring stations. Stationary automatic stations are equipped with expensive and reliable measuring devices and due to their large size and cost, these stations are deployed in limited number. Measurements in these stations are made by reference analyzers that provide very accurate measurements, but require frequent calibration and maintenance. On the other hand, portable or small static monitoring equipment are inexpensive devices that are highly portable and easy to operate with. Their lifetime is about 1-2 years.

The developed head is designed to be portable but depending on casing and power supply can be also used as a stationary device.

I. HARDWARE DESIGN

A. Electrochemical sensors

For developing of the head are used electrochemical sensors. They work in the amperometric mode, i.e. they generate a current that is proportional to the fractional volume of the toxic gas. This current is amplified, filtered and processed to obtain a calibrated reading in engineering units [4].

Generally, they include a working (also called sensing) electrode - the surface where the electrochemical reaction occurs. The working electrode either oxidizes or reduces the target gas, creating a current flow that is proportional to the gas concentration. The counter electrode balances the generated current. In most cases a reference electrode keeps the working electrode at the right potential to ensure constant sensitivity and good linearity. Some sensors also have a forth electrode that has the same functions as the working electrode. It is called auxiliary electrode. These components are in contact with electrolyte. Ambient air interacts with this electrolyte through a membrane on the top of the sensor.

Electrochemical gas sensors are designed for a specific target gas, but they also react to other gases depending on the reaction. This parameter is called cross-sensitivity. Temperature and humidity also influence over proper work of the sensor.

B. Block diagram of the sensor head

On figure 1 is shown a diagram of the multi-sensor head. It consists five sensors for 5 target gases, namely conventional (criteria) pollutant gases:

- carbon monoxide;
- nitrogen dioxide;
- nitrogen oxides;
- sulphur dioxide;
- ozone.

The multi-sensor head has a temperature and humidity sensor too. A microcontroller processes the filtered and amplified signals from the sensors and throughout an interface valid data is sent to a database. The head can be operated by direct power supply or independently on a battery.

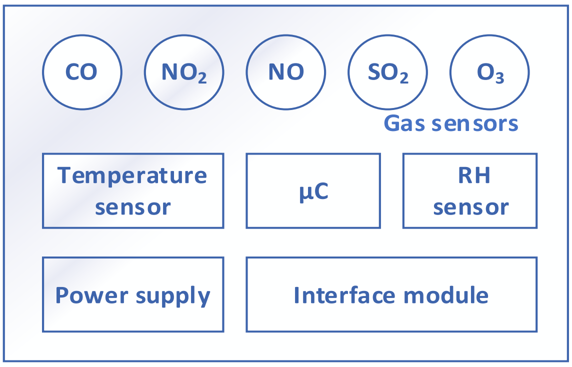

***Figure 1**. Block diagram of the multi-sensor head*

C. Schematic of the sensors

For the realization of the multi-sensor head are used sensors for the target gases mentioned before. Selected sensors are produced by the company AlphaSense. These sensors are suitable for accurate measurement of low concentrations of target gases in ambient and indoor air.

According to the manufacturer recommendations a schematic for sensors is developed and presented in figure 2.

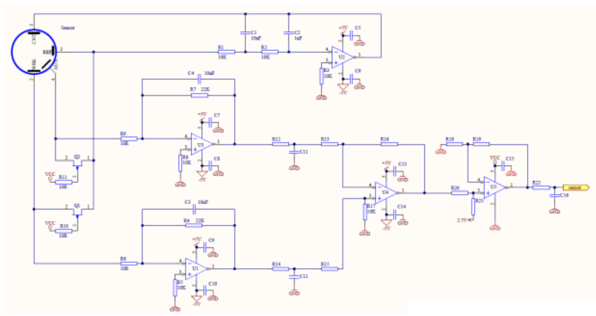

***Figure 2**. Schematic of a sensor with its potentiostatic circuit*

A typical potentiostat circuit consists of three parts [5]:

- Control circuit with bias voltage, if required;
- Current measuring circuit;
- Shorting FET to connect the working electrode to the reference electrode when power is off.

D. Control Circuit

The control op-amp (U2 in figure 1) provides the current to the counter electrode to balance the current required by the working electrode. The inverting input into U2 is connected to the reference electrode and must not draw any significant current from the reference electrode.

When switching on the circuit, the depletion mode JFET (Q1 in figure 2) goes to a high impedance state and U2 provides the current to maintain the working electrode at the same potential as the reference electrode. Any offset due to the input offset voltage in U2 will therefore cause a sudden shift in potential at switch-on. Toxic gas sensors have a large capacitance, so significant currents can flow for small potential shifts.

Circuit stability and noise reduction in the control circuit relies on R1, R2, C1 and C2.

E. Current Measuring Circuit

The measuring circuit is a single stage op amp (U1) in a transimpedance configuration; the sensor current is reflected across R4, generating an output voltage relative to the virtual earth. C3 reduces high frequency noise. It is sometimes desirable to use two op-amp stages to give the required output; the first stage should use a low value for R4 to allow the circuit to oppose the sensor current in transient conditions, followed by a second voltage gain stage to give the required output.

The measuring circuit uses a combination of the load resistor R6 plus internal sensor resistance and the internal sensor capacitance to establish an RC circuit; the selection of R6 is a compromise between fastest response time (low resistance R6) and best noise (high resistance R6).

F. Shorting FET

A shorting FET is added so that the reference and working electrodes are shorted together when power is removed from the circuit. This ensures that the working electrode is maintained at the same potential as the reference electrode when the circuit is switched off. This ensures that when the circuit is switched back on, the sensor is ready immediately. If a shorting FET is not used, the toxic gas sensor will take quite a long time to stabilize when next switched on.

On figure 3 is depicted the developed multi-sensor board which is tested with different gases.

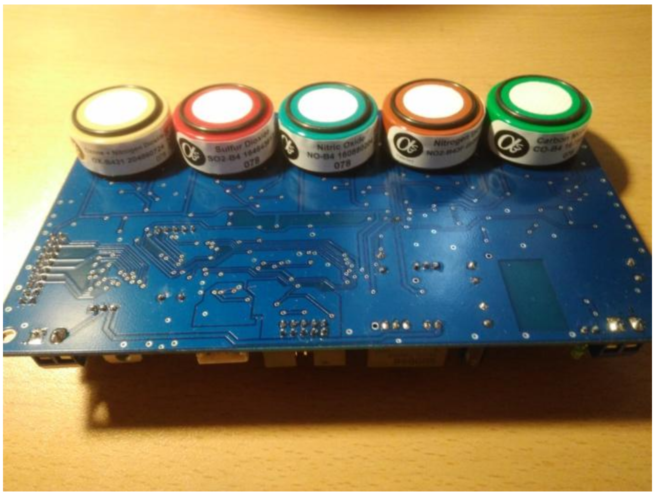

***Figure 3**. The developed multi-sensor head*

II. TESTING THE SYSTEM

The prototype is designed to give access to the signals from the sensor circuits via a single USB port. Two LabVIEW VIs are developed: one that detects, observes and transforms these signals in a suitable manner and a separate application to visualize them with a human readable value (figure 4).

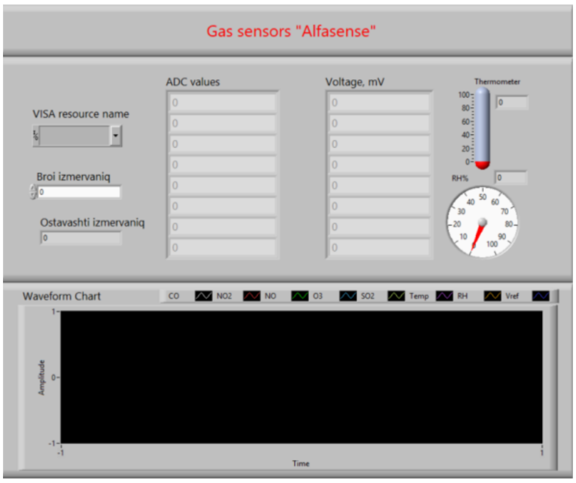

***Figure 4**. LabVIEW VI Application*

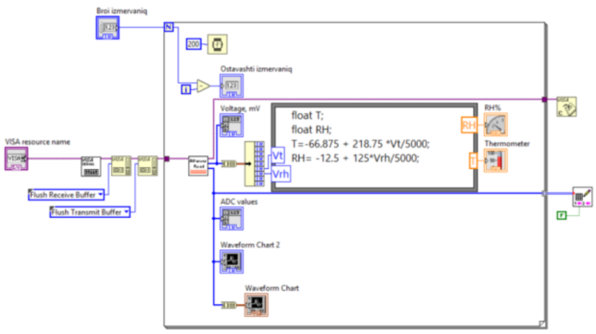

***Figure 5**. LabVIEW Block Diagram*

The Block diagram of the VIs is shown in figure 5.

The information from gas sensors, temperature and humidity sensor are measured by the microcontroller in the sensor head and after that they are send to the PC via serial communication. The raw data about temperature and humidity are converted to the real values of these quantities. All gathered data are stored in Excel file for further processing.

III. REAL-TIME MEASUREMENT RESULTS

The multi-sensor head has been presented with different gases to test its functionality. One of the results is shown in figure 6.

As seen on figure 6, sensors need some time to fix their readings - interval before the vertical marker. After presenting a gas, the target gas sensor produces more current which is depicted by the reading of the ADC of the microcontroller. In this case the sensor head is presented with carbon monoxide with concentration higher that the concentration the head is adjusted to read. It is clear that the ADC goes in saturation. Now this particular sensor needs some time to return to its normal function.

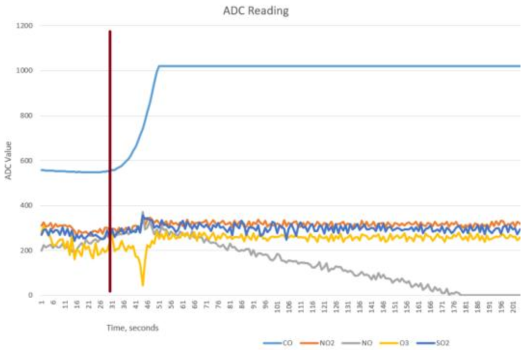

***Figure 6**. Real-Time Measurement Results*

On the picture, another sensor (nitrogen oxide) also reacts to the presented gas. This reaction is known as cross-sensitivity. This sensor will also return to its normal function after some time when the gas is not present any more.

CONCLUSION

The developed multi-sensor head shows reaction to different gases. With the developed application it is easy to read and visualize the data from the sensors and save it for further analysis. The sensor board is equipped with different interfaces allowing a connection of wifi or GSM module to transmit data to a remote database. Also it can be combined with a GPS module to track the location of the board when used as a portable device.

REFERENCE

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