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Alcohol Control: Mobile Sensor System and Numerical Signal Analysis

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Abstract: An innovative mobile sensor system for alcohol control in the respiratory air is introduced. The gas sensor included in the sensor system is thermo-cyclically operated. Ethanol is the leading component in this context. However, other components occur in the breathing air which can influence the concentration determination of ethanol. Therefore, mono-ethanol samples and binary gas mixtures are measured by the sensor system and analyzed with a new calibration and evaluation procedure which is also incorporated in the system. The applications demonstrate a good substance identification capability of the sensor system and a very good concentration determination of the components.

Keywords: Alcohol control, Mobile sensor system, Thermo-cyclic operation, Data analysis, Substance identification, Concentration determination.

1. Introduction

There is a broad field of applications for chemical analysis of gases and volatile organic compounds (VOCs) like discriminated monitoring of toxic gas leakages, online monitoring of volatile components in chemical and biochemical processes, quality monitoring in food processing, etc. In this context, metal oxide gas sensors (MOGs) are well introduced as gas sensing devices. This is due to the fact that they are very sensitive, have good long-term stability and are low in price. But on the other hand, when these sensor devices are operated isothermally, they are not at all selective. That means that they cannot be used for sophisticated analysis of gas mixtures. Therefore, other approaches are necessary like a gas sensor array of MOGs [1-2] or by thermos-cyclic operation of the MOG and simultaneous sampling of the conductance which leads to so-called "conduction over time profiles" (CTPs) [3-5]. These profiles give a fingerprint of the surface processes with the gas and represent the gas mixture under consideration. The gas specific features of the CTPs can be used for component identification and concentration determination. At the Karlsruhe Institute of Technology (KIT), many procedures were established to evaluate such signal patterns [6] and also for source localization [7].

In this report, we will introduce an innovative mobile sensor system for alcohol control in the respiratory air [8]. In this context, ethanol is the leading component. But because also other components like acetone can occur in the breathing air, we consider not only mono-ethanol samples, but also binary gas mixtures. The analysis of these samples is performed with the calibration and evaluation program

ProSens2, which is an integral component of the sensor system.

In Section 2, the mobile sensor system is described. A short outline of the calibration and evaluation procedure ProSens2 is given in Section 3. In Section 4, the data analysis is performed, including the ethanol investigation and the investigation of binary ethanol-acetone mixtures as well. Section 5 summarizes the results of this report.

2. Mobile Sensor System

2.1. Sensor System Platform and Adapter

For breath control in the respiratory air, especially for alcohol control, an innovative sensor system platform was developed. Based on this platform, an adapter for smartphones was developed for mobile monitoring of the breathing air.

This adapter consists of a combined and modular hardware- and software system, which runs an embedded metal oxide gas sensor in a thermos-cyclic mode and which determines the alcohol content on the basis of the measurement results via an innovative calibration- and evaluation procedure ProSens2 in real time. The analysis results will then be displayed on the smartphone.

2.2. Electronics for Heater Control and Data Acquisition

In order to characterize and operate semiconducting gas sensor elements with respect to the application, a sensor platform was developed which ensures a robust functioning of hard- and firmware. This platform supports a variety of commercially available metal oxide gas sensors. In this investigation, the sensor MLV from Applied Sensors [9] was used. Via its graphical user interface different parametrizable temperature cycles can be configured.

The core unit of the platform is a base-board with a powerful micro-controller communicating with external modules in a master-slave-configuration. The base-board is able to manage up to four gas sensor modules and features ambient condition monitoring.

The platform outputs the sensor raw data (basically the measured voltages), which can easily be transformed into resistances or conductances or pre-calculated values for a reduced data stream. Via USB, the platform is connected to a standard PC where the data live visualization and the storage is carried out. Via Bluetooth the platform can be connected to mobile applications running on smart phones.

For the measurements in this paper, a platform with the following specifications was used:

- The temperature control allows a set-point accuracy of 2 °C within an overall temperature range of 100 to 500 °C. The set-point can be updated every 10 ms;
- The read-out circuit features a sampling time of better than 1 ms;
- Measurement voltage accuracy is around of 5 mV (by using a 10-bit-ADC);

The dynamic range of the read-out circuit is between 1 k and 100 M.

2.3. Temperature Cycle

Based on the above-explained electronics, several temperature cycles have been applied to the sensors while being exposed to the gas mixtures.

For the experiments carried out in the scope of the publication, the temperature cycle in the following Fig. 1 has been considered.

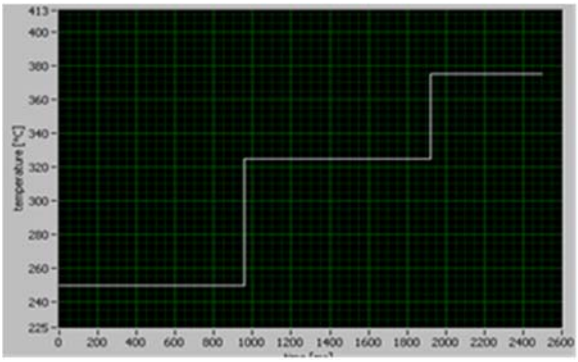

Fig. 1. Thermo-cyclic (step-wise) temperature cycle.

3. Calibration - and Evaluation Procedure ProSens2

As mentioned above, the calibration- and evaluation procedure ProSens2 is included in the mobile sensor system. ProSens2 is an updated version of ProSens [10] to meet the requirements of this sensor system. ProSens2 consists like ProSens of a calibration part and an evaluation part.

Using the calibration part of ProSens2, the mathematical calibration model is calculated based on calibration measurements. The mathematical calibration model is a parametric model and only the parameters will be transferred to the evaluation part of ProSens2.

If an unknown gas sample is measured, the evaluation part of ProSens2 performs a substance identification and concentration determination of the sample, based on the calibration parameters. For substance identification, ProSens2 calculates a so-called theoretical CTP and compares this CTP with the real measured CTP. Only if the distance of theoretical CTP and measured CTP is smaller than a pre-determined decision threshold, ProSens2 recognizes the unknown sample with the gas sample under consideration. In this case, the concentration determination will be performed.

Substance identification is very important to avoid misleading analysis results like false alarms.

4. Data Analysis

Ethanol is the leading component for alcohol control in the respiratory air. To investigate the performance of the sensor system, pure ethanol samples were analyzed in a first application.

But there can be also further components in the respiratory air which have to be considered to avoid misleading results. One of these components is the acetone in the breathing air. Acetone is an indicator for diabetes. Therefore, binary ethanol-acetone gas samples were investigated in a second application.

The measurements were performed with the above described sensor system using the cyclic variation of the working temperature in Fig. 1. The determination of the mathematical calibration models and the data analysis were performed with the included program ProSens2.

4.1. Application 1: Ethanol Investigation

To establish the mathematical calibration model with the calibration part of ProSens2, three gas samples of ethanol gas with concentrations 50 ppm, 100 ppm and 175 ppm were measured.

To investigate the performance of the sensor system and the embedded evaluation procedure, three further gas samples were measured: ethanol with 135 ppm, acetone with 2 ppm and H2 with 10 ppm.

As mentioned above, ProSens2 calculates the so-called theoretical CTP and compares this CTP with the real measured CTP. In Fig. 2, the theoretical CTP and measured CTP of the ethanol sample is plotted. It can be clearly seen, that the difference between the two curves is very small. This means that ProSens2 recognizes that this sample is an ethanol gas.

Theoretical CTP and measured CTP for acetone rsp. H2 are shown in Fig. 3 rsp. Fig. 4. In both cases, the difference between the two curves is very large. So ProSens2 recognizes that in both cases the measured sample is not an ethanol gas.

Of course, the decision for substance identification is not based on the visual impression. Therefore, a "difference value" is calculated from the sum of quadratic differences of every sample point of the measured CTP and the theoretical CTP. Only if this difference value is smaller than a predetermined decision value, ProSens2 identifies the unknown gas sample with the related calibrated gas mixture. Table 1 shows the difference value for the gas samples.

It can be clearly seen that the difference values in the blue marked fields of Table 1, which correspond not to an ethanol gas, are significantly larger than the difference value in the other field which corresponds to an ethanol gas. This means that ProSens2 is able to perform very good substance identification.

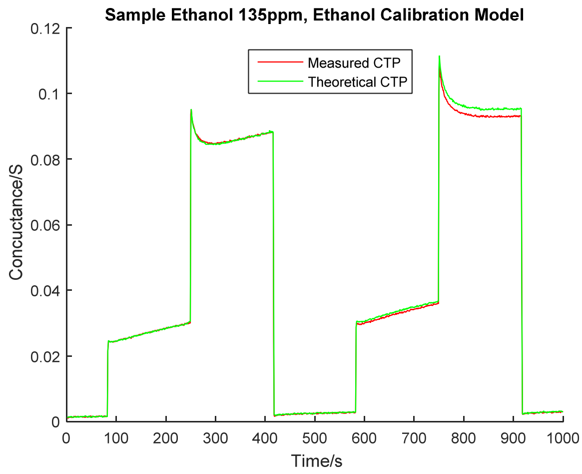

Fig. 2. Comparison of measured CTP and theoretical CTP based on the ethanol calibration model for sample ethanol 135 ppm.

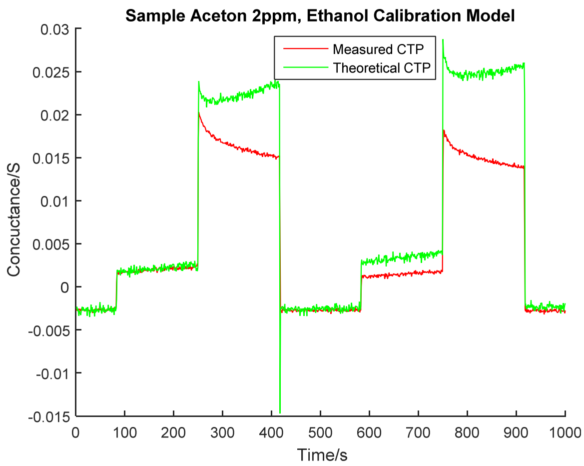

Fig. 3. Comparison of measured CTP and theoretical CTP based on the ethanol calibration model for sample aceton 2 ppm.

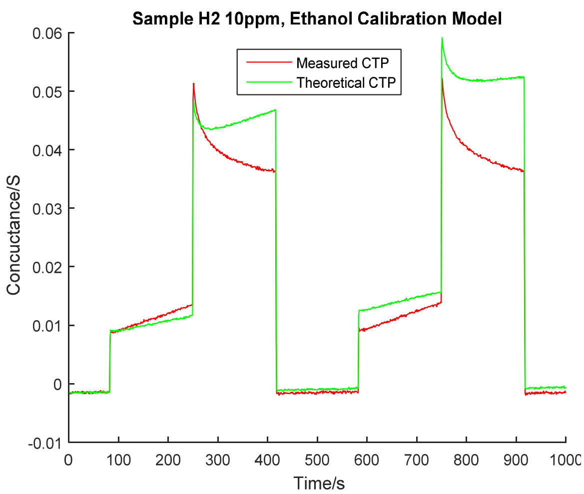

Fig. 4. Comparison of measured CTP and theoretical CTP based on the ethanol calibration model for sample H2 10 ppm.

Table 1. Difference values for the gas samples.

Ethanol 135 ppm	Acetone 2 ppm	H2 20 ppm
2.1e-05	7.8e-04	5.9e-04

After substance identification, ProSens2 calculates the concentration of the ethanol sample. Table 2 demonstrates the very good analysis result.

Table 2. Analysis Results of the Ethanol Investigation.

Dosed Concentration	Analyzed Concentration	Relative Analysis Error
135 ppm	140.2 ppm	5.3 %

4.2. Application 2: Binary Ethanol-Acetone Mixture

In a second application, binary ethanol-acetone mixtures were considered because additional components in the respiratory air can influence the ethanol concentration determination.

To establish the mathematical calibration model with the calibration part of ProSens2, the gas samples of an ethanol-acetone gas mixture given in Table 3 were again measured using thermo-cyclic operation of the sensor system.

Table 3. Gas Samples for Calibration.

Ethanol-Acetone in ppm	Ethanol-Acetone in ppm	Ethanol-Acetone in ppm
50-0.5	50-1	50-2
100-0.5	100-1	100-2
175-0.5	175-1	175-2

This means that only 9 samples were required for the establishing of the calibration model. This is a very good aspect because calibration measurements are very time consuming and expensive.

To investigate the performance of the sensor system with the evaluation procedure ProSens2, three further binary ethanol-acetone gas mixtures and two non-binary ethanol-acetone gas mixtures were measured in the same manner as the samples for calibration and analyzed together with the samples of the calibration process. The samples are given in Table 4.

The blue marked lines in this table refer to non-binary ethanol-acetone gas mixtures based on the calibration model of the binary ethanol-acetone mixture.

The following figures show again the comparison of theoretical CTP and measured CTP on the basis of the ethanol-acetone calibration model. In Fig. 5, the two curves are quite together. This means that the sample is identified as a binary ethanol-acetone mixture. In Fig. 6 and Fig. 7, the difference between the two curves is very large. That means they are not identified as the binary gas mixture under consideration.

The following Table 5 shows the difference values between measured CTP and theoretical CTP.

Table 4. Gas Samples for Calibration.

Ethanol-Acetone in ppm	Ethanol-Acetone in ppm	Ethanol-Acetone in ppm
50-0.5	50-1	50-2
100-0.5	100-1	100-2
135-0.5	135-1	135-2
175-0.5	175-1	175-2
Acetone in ppm	1	
H2 in ppm	20	

Table 5. Difference values for the gas samples.

Ethanol/Aceton	0,5 ppm	1 ppm	2 ppm
50 ppm	0.0001	0.0004	0.0007
100 ppm	0.0007	0.0006	0.0023
135 ppm	0.0044	0.0018	0.0013
175 ppm	0.0002	0.0007	0.0007
Acetone 1 ppm	0.2508		
H2 20 ppm	0.2955		

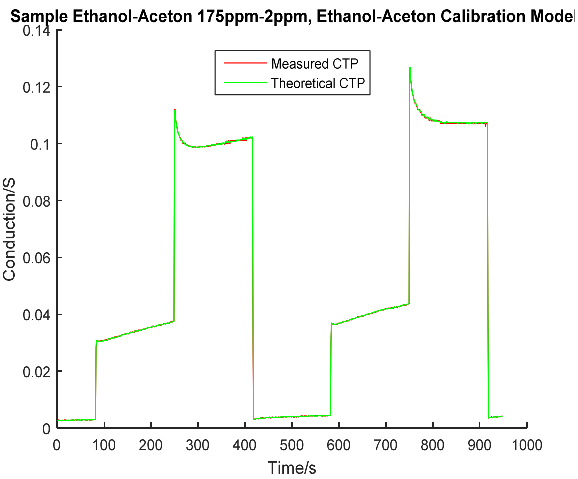

Fig. 5. Comparison of measured CTP and theoretical CTP based on the ethanol-acetone calibration model for sample ethanol 175 ppm and acetone 2 ppm.

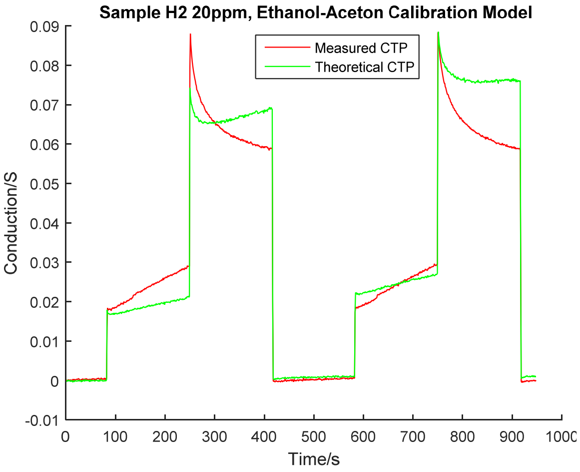

Fig. 6. Comparison of measured CTP and theoretical CTP based on the ethanol-acetone calibration model for sample H2 20 ppm.

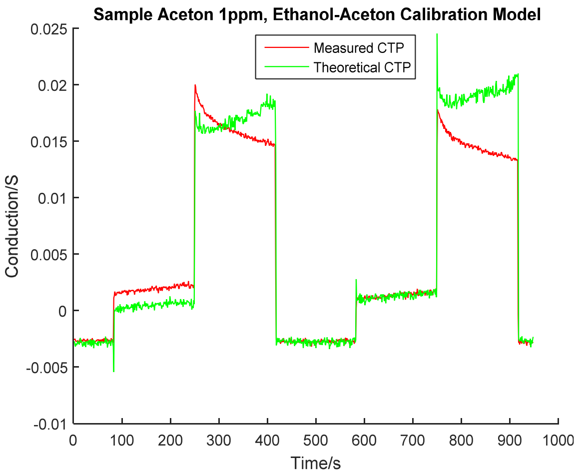

Fig. 7. Comparison of measured CTP and theoretical CTP based on the ethanol-acetone calibration model for sample acetone 1 ppm.

It can be clearly seen that the difference values in the blue marked fields of Table 5, which do not correspond to ethanol-acetone gas mixtures, are significantly larger than the difference values in the other fields which correspond to ethanol-acetone samples. This means that ProSens2 is able to perform also in this application very good substance identification.

After substance identification, ProSens2 calculates the ethanol concentration of the ethanol-acetone sample.

Table 6 demonstrates the very good analysis results even in the case of a binary gas mixture with relative analysis errors smaller than 4 %.

5. Conclusion and Future Work

In this report, a test platform for alcohol control as a pre-release of the later mobile electronics was developed which ensures a robust functioning of hard- und firmware. This platform supports a variety of commercially available metal oxide gas sensors.

Table 6. Analyzed concentration values of the Ethanol components in ppm.

Ethanol/Acetone (dosed values)	0.5 ppm	1 ppm	2 ppm
50 ppm	49.5	50.5	50.0
100 ppm	101.0	100.0	99.2
135 ppm	141.6	140.0	140.1
175 ppm	175.5	175.4	174.1

A specific aspect of the targeted application of breath alcohol detection is the reproducible generation of ethanol at nearly condensing gas atmosphere like it is assumed for breath monitoring. Operating the sensor system in a special thermo cyclic operation mode leads to CTPs which can be used for substance identification and concentration determination of the components of the gas mixture. Therefore, a calibration and evaluation procedure called ProSens2 was established. As shown in the application, ProSens2 is able to identify pure ethanol samples as well as binary ethanol-acetone mixtures in a very good manner and is also capable to determine the concentration of the ethanol samples and of the components of the ethanol-acetone mixtures with relative errors lower than 5 %.

In future work, the influence of further interfering components in the breathing air will be checked, including the interference of moisture in the respiratory air. Furthermore, the capability of the mobile sensor system for other applications will be investigated. Areas of research could be monitoring of diabetes, where acetone is the leading component, or the supervision of asthma with NO as the leading component.

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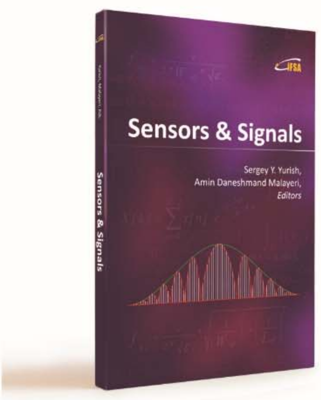

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