

# Portable Sensing of Organic Vapours based on a Single Semiconductor Sensor

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**Abstract:** A notable need for lightweight, simple-to-use portable gas analysers with facilities aimed at wide range of applications is observed in the market of measuring instruments today. In this work, a concept of portable sensing of organic vapours is presented. As the most reliable, the semiconductor gas sensor technology was chosen. However, due to high power consumption of this kind of sensors only a single sensor option is currently feasible for the portable device. In view of partial selectivity of the metal oxide based gas sensors, the unsatisfactory analytical abilities of the device could be anticipated. But, we showed that a single semiconductor gas sensor may be used for identification and quantification of the organic compounds vapours. In our solution, this goal is accomplished by applying active gas sampling. It was demonstrated that variable exposure conditions of a sensor, which are induced by the gas flow, allow for obtaining the sensor signal that has high information content. It is sufficient to characterize the test gases qualitatively and quantitatively. The achieved accuracy is very good for a screening device.

## 1 INTRODUCTION

The detection of volatile organic compounds (VOCs) or smells has become increasingly important in industry and for an assessment of indoor air quality (Postolache et al., 2005). A wide range of analytical instruments can be used for the measurement of these species today. They present different applications and performance characteristics. These equipments comprise: laboratory analytical instruments, fixed-point gas monitoring systems, portable and transportable gas analysers or detectors.

Recently, there is a widespread need for lightweight, simple-to-use portable gas analysers with facilities aimed at a wide range of applications in process control, quality control and safety in work areas of factories, research institutions and domestic premises.

Portable gas analyzers can work on the basis of different analytical methods and techniques. For example, portable gas chromatographs and spectrophotometers are used for qualitative and quantitative analysis of gaseous substances, while photoionization and flame ionization detection is

widely applied for the determination of total volatile organic compounds.

The most common gas sensing technology for the measurement of VOCs is based on metal oxide (MOX) gas sensors (Yamazoe, 2009). The prominent reasons for the selection of these devices are: wide commercial availability, relatively low price, possibility of on-line operation and high sensitivities in detecting very low concentrations of a wide range of gaseous chemical compounds. In addition, they are robust, lightweight and small. Semiconductor gas sensors also present several important shortcomings, e.g. lack of selectivity and relatively high power consumption. These disadvantages limit seriously their application in the analytical instruments, particularly in portable analyzers. In practice, this type of sensors is used for continuous, periodic or instantaneous detection of specific toxic and flammable volatile substances. They are applied first of all in fire detectors, leakage detectors, controllers of ventilation in cars and planes, alarm devices warning the overcoming of threshold concentration values of hazardous gases in the work places.

The aim of this work is to show that single semiconductor gas sensors can be used in portable

devices for identification and quantification of organic compounds vapours. This proposition is located in category of devices for screening tests. The development of this type of equipment is motivated by their wide range of applications.

## 2 EXPERIMENTAL

### 2.1 Materials

In this work vapours of volatile organic compounds (VOCs) in air were identified and quantified. The following substances were used in measurements: hexane, heptane, octane, cyclohexane, benzene, toluene, xylene and ethylbenzene. Chemicals were purchased from Sigma-Aldrich. The details about the examined concentrations are included in Table 1.

Table 1: The VOCs concentrations used in the experiments.

	Concentration [ppm]			
	25	76	151	302
Benzene	25	76	151	302
Toluene	21	64	127	255
Xylene	18	55	111	222
Ethylbenzene	18	55	110	220
Hexane	17	51	102	204
Heptane	15	46	92	183
Octane	14	41	83	165
Cyclohexane	21	62	124	249

### 2.2 Experimental Setup

We assumed in our concept that a portable analyzer based on a semiconductor gas sensor should be relatively cheap and easy in use. Therefore it is to consist of the following elements (functional blocks): (1) gas sampling device, (2) single sensor installed in a measurement chamber, (3) voltage supplier, (4) interface circuits containing a load resistor for an electrical signal generation, (5) digital voltmeter, (6) data acquisition card, (7) display, (8) user interface, (9) software for signal processing and pattern recognition tasks implemented.

This concept was tested using an experimental setup. The sampling device consisted of a diaphragm pump and a rotameter. It was used to measure and control the flow rate of the gas sample. Sensors were placed inside measurement chambers, individually. Small, airtight measurement chambers were made of aluminium. They were specially designed for flow-type measurements. The measurement chambers were fitted with all the necessary pneumatic and electrical connections. Fifteen commercially

available Taguchi Gas Sensors made by Figaro Engineering Japan were tested in this work. These were: TGS 821, TGS 822, TGS 824, TGS 825, TGS 826, TGS 880, TGS 883, TGS 800, TGS 2201 (gasoline), TGS 2201 (diesel), TGS 2106, TGS 2104, TGS 2602, TGS 2620 and TGS 2600. The sensors were chosen because of their satisfactory performance, e.g. sensitivity, response time, robustness, low price and simplicity of use in many applications involving measurements of volatile compounds at different concentrations. The sensor was connected to the voltage supplier and the interface circuits containing a load resistor. The proper working temperature of the sensors was assured by applying constant voltages to their heaters. The values of the heaters voltages were selected in accordance with the recommendations of the sensors' producer. These were: TGS 821 (5 V), TGS 822 (5 V), TGS 824 (5 V), TGS 825 (5 V), TGS 826 (5 V), TGS 880 (5 V), TGS 883(5 V), TGS 800 (5 V), TGS 2201 (gasoline) (7 V), TGS 2201 (diesel) (7 V), TGS 2106, TGS 2104 (7 V), TGS 2602 (5 V), TGS 2620 (5 V) and TGS 2600 (5 V). The data on the actual sensor operating temperatures while applying these heater voltages was not available. The lower bound of the operating temperature range, usually quoted for semiconductor gas sensors in general, is 350 °C. For the measuring purposes, the load resistor was selected separately to each sensor. The voltage variations measured on the load resistor by voltmeter constituted the sensor output signal. The experiments were carried out at a constant bias voltage. The data acquisition card converted the output signal into digital numeric values which were manipulated by a computer. The signal sampling was performed every 1 s.

The important element of each measurement system is a calibration procedure. The preparation of gas standards is a key issue in a case of gas analyzer calibration. We proposed the procedure, which can be routinely exploited in each laboratory. The evaporation method was applied for preparing gas mixtures of the predefined composition (Szcurek et al., 2013). It consisted in evaporating the defined amount of liquid analyte into the known amount of purified air, collected into the tedlar bag. The concentration of the analyte was determined by its dosage, the airflow and its duration. The evaporation method was successfully validated by comparing it with a Kin-Tek gas standards generator (491 M).

### 2.3 Description of the Operation Mode

In this work we have focused our attention on the

dynamic response of the sensor exposed to the test gas in various physical and chemical conditions. The operation mode was based on the measuring procedure which consists of three, sequentially performed stages. The duration of each stage was 420 s and this time was fixed for all measurements (see Fig. 1). However, in general, different durations may be chosen. Before the sensor exposure to gas under test this device attained a steady state in the stream of pure air. The first step of the operation mode consisted in the dynamic exposure of the gas sensor to the stream of air which contained the organic compound vapours. The test sample was delivered to the sensor chambers and it was allowed to continuously flow through. The gas flow rate in the sensor system was kept constant (1 l/min). During the second phase of operation, the gas flow was stopped and the sample was retained in the measurement chamber. The last step of the operation mode had two functions: the gas sensor recovery process occurred and the analytical information was also acquired. The gas line and the measurement chamber were cleaned with a stream of pure air. A constant gas flow rate was maintained during that operation.

### 3 METHODS

The key issues in the development of portable analyzers, based on a semiconductor sensor, are the methods used for: (1) gas sampling, (2) conversion of chemical entity into the analytical signal, (3) feature vector construction, (4) identification and quantification of the test sample.

#### 3.1 Gas Sampling

Gas sampling is one of the most important stages of a measurement process (Conner et al., 2006). In sensor systems it can be based on a natural diffusion or on the dynamic method. Generally speaking the diffusive sampling is preferred when limitations in dimension, payload or energy consumption do not allow the adoption of a sampling system where the sensors are hosted in a chamber with controlled airflow, temperature and humidity.

An active sampling involves an air mover to draw a sample into the instrument, where it enters the sensor chamber for analysis, and is then exhausted back to the atmosphere or a vent line (Lodge, 1989). In this approach the sensors are enclosed inside a chamber, where the environmental conditions and gas exposure times are known and

controlled. Usually the gas sample is automatically aspirated by the motor driven pump at a prescribed rate for a prescribed time. The intrinsically safe or explosion-proof pump has to be employed in some applications. The active sampling is performed by a suitable pneumatic system. It consists of a sample probe and a delivery system which is designed to transfer the gas from the source to a sensor array. Usually, the delivery system includes a gas line, flow indication, valves to control sample draw and calibration gas delivery, a gas mover (e.g. a pump or a fan). All gas sensors measure partial pressure, and a sample actively brought to the sensor is at a slightly elevated pressure, while a diffusion sensor operates at ambient pressure, therefore the output sensitivity of the sample draw sensors is usually higher than in case of diffusion sensors. This can be important for many toxic gases with low regulatory levels. The active sampling is pretty much independent of environment conditions. When diffusive sampling is applied, the sensors are located at or near the points where there is the possibility of gas release. However, among many detection points of typical application, there may be locations that are simply not suited to a sensor installation, either because one cannot be mounted close enough, or the maintenance would be difficult or impossible at that particular spot. In this case the sample draw system is the most appropriate. The advantages of active sampling caused that in our concept this approach was chosen. The power consumption of a micropump may be estimated based on the demand for the voltage supply in a range from 3.2 to 26.0 VDC and for the average current of 130–180 mA.

#### 3.2 Conversion of Chemical Entity into an Analytical Signal

Two factors decide about the conversion of chemical entity into an analytical signal in portable gas analyzers: sensors and operation mode. Majority of semiconductor gas sensors are not selective enough to detect a single chemical species in gaseous mixture, because of limitations originating from the principles of the sensing mechanism (Yamazoe and Shimanoe, 2011). The resistance responses of these devices to the tested gases are induced indirectly through oxidation reactions occurring over the sensing materials. As it is impossible to oxidize only one specific gas in a mixture of reducing gases adsorbed by the sensing layer, sensor response may be influenced by many constituents of gaseous mixture. This disadvantage cannot be eliminated completely, but there are methods to improve the

selectivity of semiconductor gas sensors. One of them is based on a sensor array (Szcurek and Maciejewska, 2012).

This approach is established on an assumption that cross-sensitivity of the gas sensors is unavoidable. Static signals include one-dimensional information; therefore they are inadequate for distinguishing between the response to a target gas and to other interfering chemical species. For that reason, instead of trying to eliminate this feature, partially selective semiconductor gas sensors are linked as independent sensing elements in an array configuration. The selectivity of each sensing element is admittedly low, but the combination of the responses of different sensors presents a characteristic pattern that can be treated as a unique ‘signature’ (“electronic fingerprint”) of individual chemical species. A subsequent signal processing and pattern recognition techniques allow for extracting both qualitative and quantitative information about the composition of the measured mixture. In practice, the number of individual gases that can be quantified using any sensor array is at most 2 – 3.

Traditional sensor arrays cannot be applied in the portable devices, because of high power consumption. Semiconductor gas sensors are the devices which have to operate at high temperature for achieving the desired sensitivity and selectivity to the gases under test. Depending on the material used and the gases that need to be detected, typical operating temperatures are between 300°C and 900°C. In commercial portable analyzers, power consumption has to be minimized, because batteries are usually the only and unavoidable power source that can be used with these devices. Thus, the main effort must be focused on finding the best power-optimization strategy to permit the device to operate as long as possible.

One of the strategies is based on instruments which are designed with low power sensors. The power consumption of the metal oxide gas sensors varies based on the design of these devices. A simple semiconductor gas sensor is basically composed of a substrate in alumina or silicon (on which the sensing layer is deposited), the electrodes (to measure the resistance changes of the sensing film) and the heater (commonly a Pt resistive type heater) to reach the optimum sensing temperature. Sensors on Si bulk substrates (quartz glass spacer as heat sink, contact via Au bonding) require approximately 1.3 W of power (at 350°C). The power consumption can be reduced to approx. 700 mW, when a sensor is suspended in housing and

contacted via Pt welding. One of the most broadly utilized semiconductor gas sensors is the semiconductor gas sensor based on tin oxide ceramic, which is commercialized by Figaro, Japan. Even though this material is very reliable and shows a good stability of the sensing properties, its disadvantage is high power consumption, from 400 mW to 1 W (Table 2), due to heating the massive ceramic tube. This level of power consumption has a limit for the sensors to be adopted in a battery operation portable device.

The most effective method to reduce power consumption is by the thermal decoupling of the sensor from the housing, for example through the use of micromechanical structures (micromachined heaters), called “micro-hotplates” and contact via Au bonding (Semancik et al., 2001). The characteristic feature of these structures is the active area that comprises a heater, sensor electrodes and the gas sensitive layer situated in the centre of a thin membrane, which itself is supported by an outer frame, made of silicon.

Table 2: Power consumption of the most energy-consuming element of the semiconductor gas sensors. There are listed TGS sensors used in the experiments.

Sensor	Heater power consumption [mW]
TGS 821	660
TGS 822	660
TGS 824	660
TGS 825	660
TGS 826	833
TGS 880	835
TGS 883	1000
TGS 800	660
TGS 2201(benzene)	505
TGS 2201(diesel)	505
TGS 2106	539
TGS 2104	640
TGS 2602	280
TGS 2620	210
TGS 2600	210

The resistively heated dielectric membrane provides the thermal insulation between the active area heated up to high temperature and the silicon. This approach allows for a low power consumption, not exceeding 150 mW for operation at 450°C, and 0.3 – 15 mW for operation at 300 °C (Kimon et al, 2001). This small amount of heating power is caused by the reduction in the heated surface area as well as by the excellent thermal isolation provided by the



thin dielectric membranes. On the other hand, silicon micromachined gas sensors show some drawbacks which prevent them from accessing the high volume market. For example, the robustness of the device is lower than in case of the alumina devices.

Our proposition is based on an assumption that the successful using of the sensor array requires the availability of significant energy resources. The level of power consumption 100–200 mW seems to be good enough for the battery powered portable device, which is able to run for about 10 h without recharging the battery. Therefore, the sensor array is exchanged into the “*virtual sensor array*”, which comprises an appropriately selected single sensor and a measurement procedure. Our approach was inspired by the temperature modulation, which was proposed to increase or decrease sensor sensitivity and selectivity towards specific gases. In (Raman and Gutierrez-Osuna, 2004) there were presented virtual sensors created from single temperature modulated MOS sensors by varying the operating temperature. The temperature modulation technique is particularly interesting for metal oxide sensors as their selectivity is greatly influenced by the operating temperature (Gutierrez-Osuna et al., 2001).

Different volatile substances have characteristic optimum oxidation and reduction temperatures and therefore they give rise to characteristic resistance-temperature profile. It means that for each analyte and semiconductor gas sensor there may be determined the characteristic relationship between the sensing material resistance and temperature. Thus if the response of one sensor is measured at  $n$  temperatures, the sensor response to gas under test becomes analogous to an array of  $n$  “*virtual sensors*”. In other words, the information content of a measurement with one single sensor can be dramatically increased when the temperature modulation is applied. A survey on temperature modulation can be found in (Lee and Reedy, 1999).

The major drawback of this method is the poor repeatability of the output signals. Besides, it requires a precise temperature control and additional equipment. Therefore we proposed another approach. It is based on the assumption that  $n$  “*virtual sensors*” can be distinguished by the simultaneous diversification of a wide spectrum of working parameters and operating conditions in a given period of sensor exposure to the tested gas. In practice, this idea was accomplished by the suitable operation mode. This term means a manner or the way employed to operate a device. In practice, it is a description of conditions under which the analytical

equipment works. Usually, the operation mode is characterized by an applied procedure, sensor environment, method of sensor response (output signal) measurement and working parameters. The operation mode may affect the performance characteristics of semiconductor sensors since it determines the state of these devices during measurements. In our concept, “*virtual sensors*” originate from the rapid change of sensor exposure conditions to gas under test.

The operation mode applied in this work is illustrated in Fig. 1. It is characterized together with the typically obtained shape of the output signal. The first stage of operation mode consisted in dynamic exposure of the sensor to the tested sample. During this stage, the output signal was strongly affected by the kinetics of the processes which evoked the gas sensor response (Nakata et al., 2001). Initially, the concentration of the test gas quickly increased in the measurement chamber, which also caused gas concentration change at the sensing surface. The semiconductor conductivity changes were caused by properties of the gas surrounding and interacting with the sensing material of the sensor as well as by a number of time-dependent processes such as: the transport of the reactive species into the sensor surface, the diffusion of gas molecules inside pores of the sensing material, adsorption and desorption, the catalyzed red-ox reactions on the surface of the sensing layer (mainly their kinetics) and the electrical/electronic effects in the semiconductor. At the very beginning of the test gas delivery, the sensor signal rapidly increased. Later, the atmosphere around the sensor stabilized, which allowed for attaining dynamic equilibrium and a quasi-steady state of the sensing material. During the second phase of operation, the gas flow was stopped and the sample was retained in the sensor chambers. In this period of time the sensor temperature and the partial pressure of the analyte in the sensor chambers were continuously changed due to oxidation reactions taking place at the sensing surface. The associated sensor output signals usually exhibited decrease in time. The rate of decay was approximately constant. During the last step of the operation mode, the sensor was again in dynamic conditions. The processes, which influenced the output signals, were similar as during the first stage. However, the chemical composition of the gas stream was changed due to the test compound removal from the sensor chambers. The dynamics of the sensor signal was initially high, followed by an asymptotic decrease towards the sensor signal baseline.

Three advantages decided that we proposed this mode of operation. (1) It may be easily performed. (2) The alteration of the sensor exposure conditions causes the change of many working parameters. Each of these changes encodes additional chemical information in the output signal. (3) The alteration of the exposure conditions does not induce deep change of the sensor physical state. Therefore the performance characteristics can be quickly recovered.

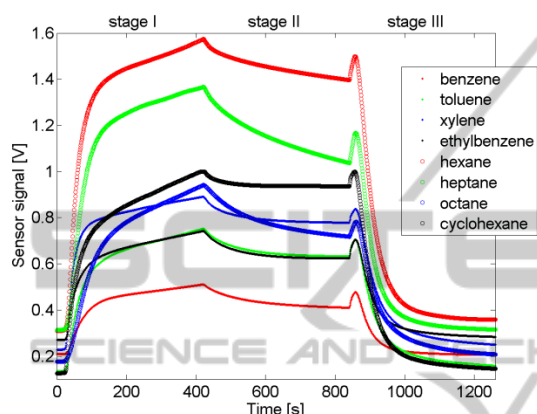


Figure 1: The output signal of TGS2600 recorded when applying sensor operation mode presented in this work.

The non-linear, transient signal induced by the alteration of the sensor exposure conditions to gas under test is a source of chemical information, because it is a function of variables such as: physical and chemical properties of the target gas, concentration and time of the sensor response. Each change of exposure conditions affects the characteristic shape of the transient signal that depends on the particular analyte to which the sensor is exposed. Therefore, signal measured in unsteady state of the sensing material conveys multi-dimensional information leading to an enhancement in the discriminating ability of the gas sensor. This fact allows create "virtual sensor array". In our approach, each "virtual sensor" is determined by the strictly defined time point of the sensor response. In other words, "virtual sensor array" is a set (collection) of data that represent discrete values of the output signal in a function of time. It refers to a large number of distinct responses gathered from a single sensor. It is obvious that by combining data from different "virtual sensors" one can obtain more information about a given gas mixture than an individual sensor signal would provide. Since pattern classifiers are blind to the physical source of their data, "virtual sensor array" may be used to generate the patterns of target gas in a portable

analyzer. Compared to the conventional approach, virtual sensor array based on one-single sensor offers low power consumption, volume and cost, which open new markets for portable devices.

### 3.3 Feature Vector Construction

The output signal of a single sensor is defined as the time-ordered sequence of measurements, which convey information. Usually, signal processing is performed in order to extract this information. This operation is a complicated process and it consists of baseline manipulation, data compression, dimensionality reduction, feature extraction or selection. In our work, the sensor signal is considered as a "virtual sensor array". It means that the feature vector is a combination of the responses of "virtual sensors". The requirements considering simplicity of the portable analyzer cause that none feature selection is performed in our approach. The feature vector consists of raw measurement data obtained in response to the test gas.

### 3.4 Identification and Quantification of the Sample

In our concept it is assumed that the portable device is able to identify the kind of organic vapours and to determine the concentration category. Both problems are solved using a classification approach. In the first case, the class is defined by the kind of the chemical compound. In the second case, the class is defined as a concentration range.

We accomplished the classification task using the  $kNN$  classifier (Polikar et al., 2001). This method was chosen for a number of reasons. First of all,  $kNN$  is the best known non-parametric approach to classification. It is favourable when the probability distributions in distinct classes are difficult to estimate. One faces this problem in particular, when the number of training patterns is relatively small. This case is frequently encountered in gas sensor measurements, because the collection of numerous patterns may be very time consuming. Second, the  $kNN$  classifier actually lacks the training phase and all calculations are deferred to the classification stage. That simplifies its application. The principle of classification is quite simple. Basically, in order to classify a test pattern the closest  $k$  patterns are found in the training dataset. Following, the class which is predominant among these  $k$  labelled neighbours is selected as the class of the investigated pattern. The algorithm which realizes  $kNN$  classification is simple mathematically and it may be

easily implemented in a microcontroller. This is very important, due to numerous criteria the portable device has to fulfil, especially the ones regarding size, weight and easiness of operation.

On a number of occasions the *kNN* method was shown to offer very good classification performance in qualitative gas recognition based on sensor measurements (Alippi et al., 2006; Maciejewska et al., 2010; Perera et al., 2002; Szczurek et al., 2011). An interesting example of quantitative application was the discrimination of gases based on concentration categories by means of adaptive *kNN* (Roncaglia et al., 2004).

In our examinations, the only parameter of *kNN* method was  $k=2$ . This choice assured best performance of the classifier.

In this work, the training data was prepared in a way to account for the potential deficiencies of the measurements performed with a portable device. We assumed that when measuring the same test gas on a number of occasions, the sensor signal may shift around the original record. The magnitude of the shift was taken from the normal distribution with the zero mean and the standard deviation equal 30 % of the steady state sensor signal value. By this operation, the original training data set was increased fifty times.

The classification performance was evaluated in terms of misclassification rate using ten-fold cross-validation procedure.

## 4 RESULTS AND DISCUSSION

The gas sensing performance, when using a single sensor, was examined in respect of recognizing the kind of organic vapour and the concentration category. Every VOC (Table 1) was recognized in a framework of one-against-all classification problems. Regarding quantitative assessment, there were defined four concentration categories for each VOC. The kernels of categories were the concentrations shown in Table 1. They could be interpreted as corresponding to: low, medium-low, medium-high and high concentration range.

Assuming the variability of the information content along the sensor signal, we compared the gas sensing performance utilizing entire sensor signal and its fragments associated with different stages of exposure (I, II and III). For each classification problem three best sensors out of fifteen were found, involving at least one sensor with low heater power consumption (Table 2).

The misclassification rates achieved when recognizing the kind of organic vapour are shown in Fig. 2 to Fig. 5. The classification errors associated with the concentration category recognition are presented in Fig. 6 to Fig. 9. The names of chemical compounds were abbreviated in the following way: Benzene (B), Toluene (T), Xylene (X), Ethylbenzene (E), Hexane (Hx), Hepatne (Hp), Octane (O), Cyclohexane (C).

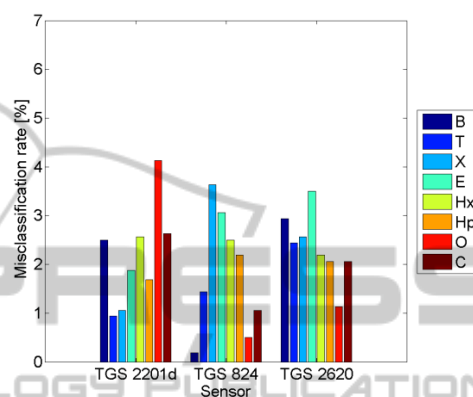


Figure 2: The error of VOCs identification based on the entire single sensor output signal. The results for three best sensors are shown.

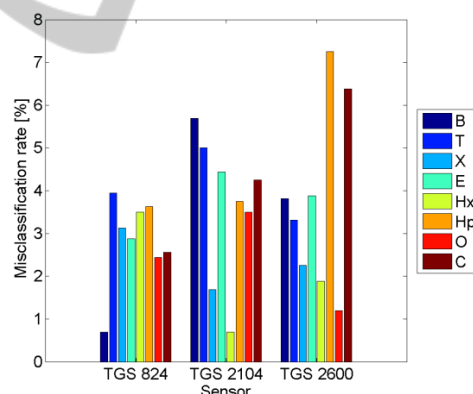


Figure 3: The error of VOCs identification based on part I of single sensor output signal. The results for three best sensors are shown.

It is important to note that variable sensor exposure conditions play the crucial role in the single sensor based gas sensing. This fact was demonstrated by comparing the misclassification rates achieved when using an entire sensor signal as opposed to its parts as the basis for gas recognition. The results were best when the first approach was utilized (Fig. 2 and Fig. 6). In case only partial information i.e. associated with a fragment of the

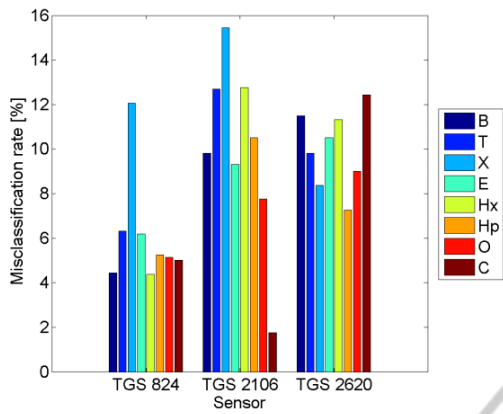


Figure 4: The error of VOCs identification based on part II of single sensor output signal. The results for three best sensors are shown.

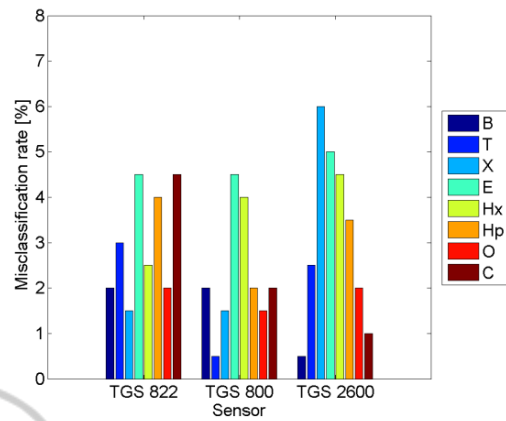


Figure 7: The error of determining VOCs concentration category based on part I of single sensor output signal. The results for three best sensors are shown.

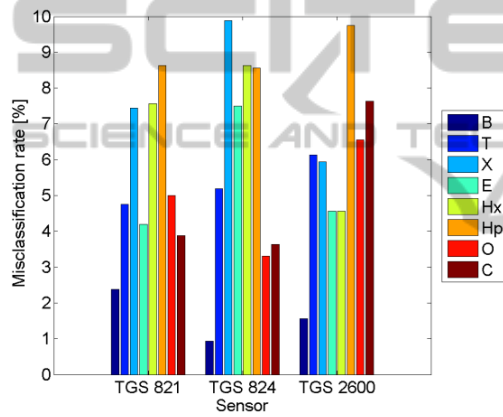


Figure 5: The error of VOCs identification based on part III of single sensor output signal. The results for three best sensors are shown.

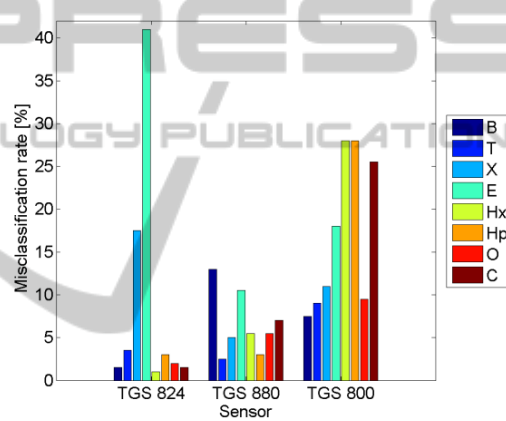


Figure 8: The error of determining VOCs concentration category based on part II of single sensor output signal. The results for three best sensors are shown.

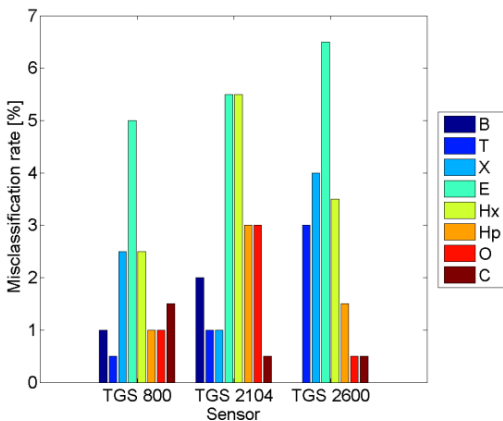


Figure 6: The error of determining VOCs concentration category based on the entire single sensor output signal. The results for three best sensors are shown.

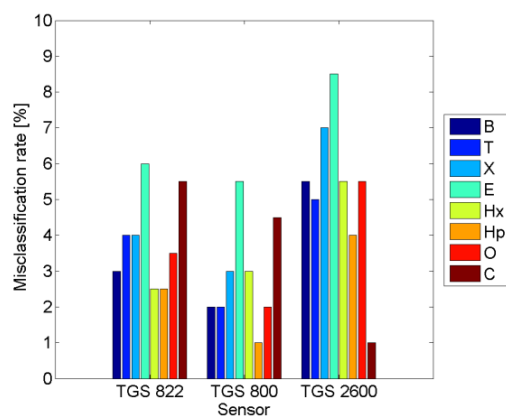


Figure 9: The error of determining VOCs concentration category based on part III of single sensor output signal. The results for three best sensors are shown.



sensor signal was available to the classifier, the performance usually decreased. The most worthy contribution to high performance gas sensing came from the dynamic exposure conditions, causing fast change of the sensor signal both, when rising (Fig. 3 and Fig. 7) and when decreasing (Fig. 5 and Fig. 9). In this approach the static exposure conditions were least informative (Fig. 4 and Fig. 8). The obtained results promise that the measurement period in the single sensor portable device may be shorter than we originally thought. It may be achieved by eliminating the middle part of the operation mode, i.e. stopping the gas flow.

Based on our studies, the single sensor gas sensing may be effectively performed with low energy consumption sensors. Overall, the best sensor of this group for recognizing the gas type was TGS 2620 (Fig. 2). The concentration categories were best delimited by with TGS 2600 (Fig. 6). The heaters of both sensors consume 210 mW each. It proves the technical feasibility of the concept of the battery powered portable gas sensing device.

## 5 CONCLUSIONS

The concept of the portable gas sensing device was presented in this work. It was assumed that the semiconductor gas sensors shall be applied in our solution, as this technology guaranties the best reliability. However, due to high power consumption required for maintaining the adequate temperature of the sensing layer, more than one sensor of this kind is not allowed in the instrument. The portable character of the device imposes strict power consumption restrictions. Therefore, a prerequisite for the feasibility of the concept was the successful identification of gases and/or the concentration categories determination using the single sensor approach.

We showed that the prerequisite may be satisfied. The crucial factor for achieving this goal was to apply the active sampling approach in the gas sensing device. It allows for altering sensor exposure conditions in time. As a result of variable exposure conditions the sensor signal may be considered as a response of the "virtual sensor array". We showed that the information content of this data was sufficient to recognize different volatile organic compounds and to determine the concentration categories for the gas samples. The achieved assessment error was less than 5 %. The portable sensor device with such performance characteristics well fits the existing market niche.

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