A Graphical Approach to Estimation of Gas Concentration with SnO_2 Sensors

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*Abstract-*Electronic systems for automated monitoring of the presence of dangerous gases are available nowadays in different configurations and with quite different capabilities. This work is presenting the development of an electronic instrument for monitoring the level of two gases (namely CO and CH_4) aiming for possible use in coalmines. The instrument is using SnO_2 sensors and is based on a graphical estimation of the concentration of each of the two gases realised by a combination of the information from the calibration curves of the two sensors. In this way, instead of trying to suppress the well-known secondary sensitivity of these gas sensors, this method is estimating the two concentrations by a computerised approximation of the operating point on the calibration curves.

I. Description of the problem

Modern technology of sensors offers different types of gas sensors, depending on the application requirements and restrictions. A realistic selection between the commercially available types of sensors for this specific application of monitoring gases in coalmines has resulted to the SnO_2 type of gas sensors. The main reasoning for this choice is due to their key characteristics: well-known, rather cheap, compatible with modern semiconductor technology and electronic circuits, etc. The two sensors used in the present investigation are SnO_2 sensors sensitive to carbon monoxide and methane from "Figaro Sensors" manufacturer (types TGS822 and TGS813 respectively). The main disadvantage of this kind of sensors is related to their poor selectivity; they are sensitive to other gases as well [1,2,3,5,7]. It is for the reason of poor selectivity of the sensors, that the research work is focused on the development of a method of processing the information from two different SnO_2 sensors used is this instrument. A good number of research reports have been published over the last years on this subject, and different solutions have been proposed [1,3,6,8]. Temperature modulation [1,4,6], multi-sensors arrays [2,3], and software based processing [3,6] are the most significant approaches to this problem. The main parameter related to the modification of the behaviour of the SnO_2 sensors is their operating temperature. A previous set of experimental measurements was focused on the influence of the operating temperature of the sensor to its sensitivity to each one of the gas components [7,8]. The present team has been studying this problem for some time now, and has proposed also an analytical method for processing the two-dimensional measurement information from such a pair of sensors [9]. This work is devoted to a different - graphical - approach, which permits the estimation of the concentration of each of the two gases, even in case where a detailed calibration procedure is not performed and mathematical information about sensors behaviour is not available.

The present work reports a novel, different approach on the use of two typical SnO_2 sensors in an automated, microcontroller-based instrument for the measurement of concentration of carbon monoxide and methane. The desired operating point for each sensor is determined first by experimental measurements of selectivity versus operating temperature, and then is followed by multiple measurements of sensors characteristics at various combinations of concentrations of the two gases. Based on these results, a method for processing the information from the two sensors is proposed, which offers a good estimation of the concentration of each one of the two gases. This new approach permits the analysis of output information from sensors sensitive to two independent input parameters (two-dimensional sensors), and provides a microcontroller-based technique of estimating two different output parameters from a pair of such sensors. A measuring instrument is developed and has been successfully tested for proper implementation of the proposed method.

A. Determination of operating conditions

The two sensors used in the present investigation are SnO_2 type sensors sensitive to carbon monoxide and methane from "Figaro Sensors" manufacturer (types TGS822 and TGS813 respectively). These two types of sensors were tested in an experimental setup for calibration of gas sensing devices. The setup includes a small chamber with fully controlled gas concentration and humidity environment by means of a series of digital mass flow controllers from BROOKS firm. The operating conditions in this chamber can be fully defined according to the desired measurement conditions, and then all other parameters (like heating voltage or output resistance value) are monitored by appropriate electronic instruments.

A previous set of experimental measurements was focused on the influence of the operating temperature of the sensor to its sensitivity to each one of the gas components [8]. It is known from previous work of other teams that the influence of the sensor temperature has to be checked individually for each kind of sensors. In short, by operating each one of these sensors in a different temperature, one gets a fairly good pair of sensors for selectively measuring the concentration of the two gases of interest (CO and CH_4). The overall selectivity achieved is adequate only for certain applications. Our interest in this phenomenon is focused though, in an entirely different possibility besides the well-known changes of cross-sensitivity and enhancement of the selectivity of the device. Further improvement in measurement performance is possible, by processing the information of both sensors, which have significantly different sensitivity factors for their primary and secondary inputs respectively. This is the focus point of this procedure, which is not aiming to the direct suppression of the sensor response to the secondary input. The operating conditions of the two sensors are chosen so that the sensitivity factors are set to considerably different levels, with a clear influence from both inputs. The processing method may be applied more effectively in this case, and may provide an accurate estimate of the concentration of each one of the two gases based on the output conductance value of each one of the two sensors.
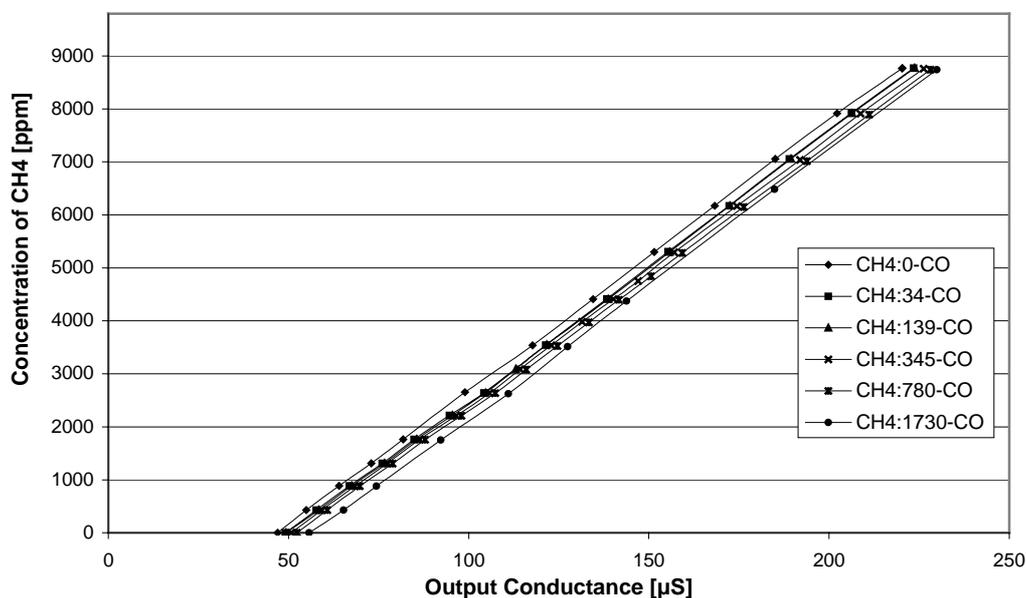

Fig. 1. The input-output characteristics of the first sensor (TGS813)

B. Analysis of the graphic approximation

The main problem encountered when using the SnO_2 type of gas sensors is related to their cross sensitivity to two different gases. Due to this fact it is difficult to distinguish the type of the gas that is detected and that is causing the output reading of the sensor. This situation is presented effectively to

input-output experimental diagrams for each of the sensors, where the primary input appears on the vertical axis, the output variable (conductance) on the horizontal axis, and the secondary input appears as a parameter characterizing the family of curves (Figs 1 and 2).

Note that the output information is presented as conductance changes instead of resistance since the resolution achieved by this form of presentation is better due to the nonlinear variation of this parameter [9]. As shown in these figures, the measurement capability of such a sensor in terms of concentration of the two gases is rather poor, since each output value may correspond to any of the lines of the family. The experimental setup for calibration of gas sensing devices includes a chamber with fully controlled gas concentration and humidity environment by means of a series of precision digital mass-flow controllers.
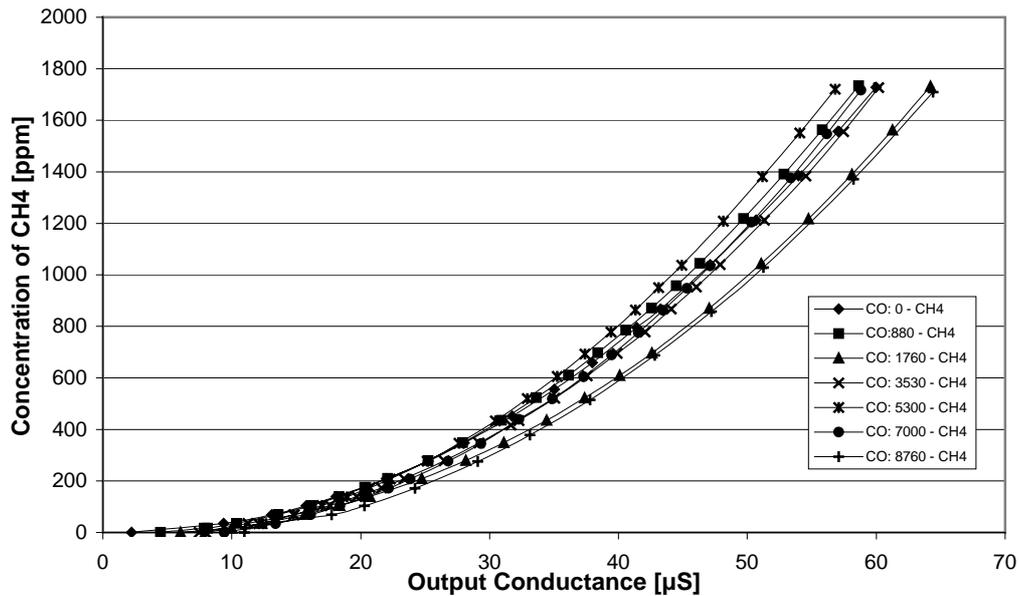

Fig. 2. The input-output characteristics of the second sensor (TGS822)

II. The proposed method

The proposed approach is based on a graphical method of presenting the problem and obtaining a solution. Therefore it is consequently presented in the same way. From the diagrams in figures 1 and 2 it is easy to extract the polynomial equation of each curve. The goal of knowing these equations is to achieve the ability to calculate the concentrations of a gas in relation with the value of the resistance of sensor and the concentration of the other gas.

The graphical method, which is used to determine the concentrations of two gases, is based on the two diagrams and on the equations of the curves. So according to the conductance of the sensor TGS 813 and knowing the minimum and the maximum concentration of the CO, it is possible to estimate (calculate) a certain range for the concentration of the CH_4. At this first step of the approximation procedure, the unknown concentration of CH_4 may be located between a known range of values as shown in figure 3 (between X1 and X3). Then in a second step, one may use the new limits of CH_4 and the proper equations to the second diagram for the sensor TGS 822, to calculate the new limits for the CO (is between Y2 and Y4). So after the second step the range of values of the concentration of the CO is smaller. Knowing the new limits for the CO and moving to the first diagram again, one may calculate the new limits for the CH_4. The new range of values is again smaller than the first one, and as the above method may be repeated many times, the effective possible range of the two concentrations of the two gases becomes smaller and smaller. In cases where there are adequate calibration curves for each gas and for each sensor, the final limits (range of values) will become quite small and at the limit is approximating to a certain value.

CH4

X

X3

X1

Y1

Y2

Y3
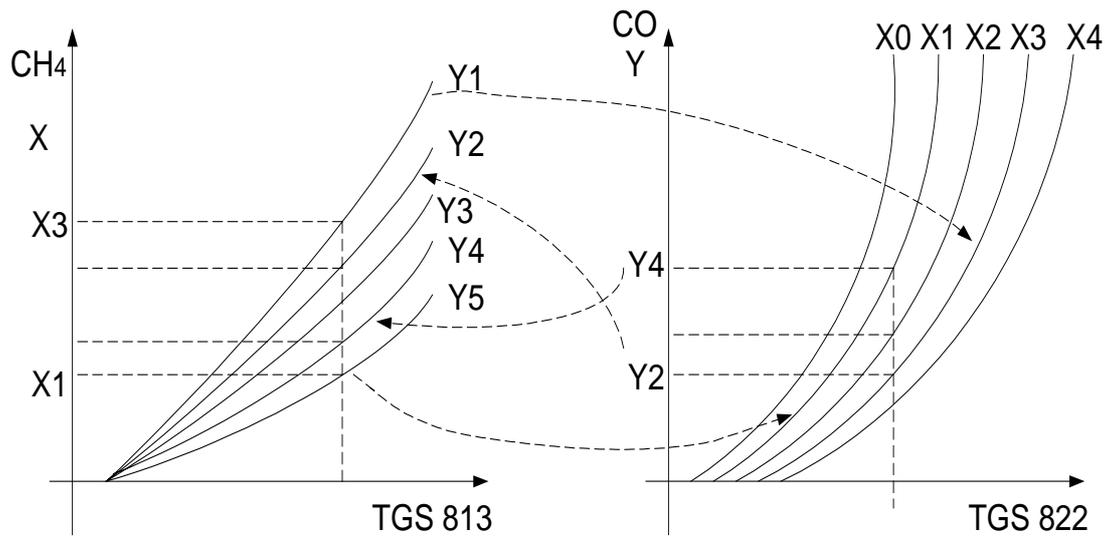
Y4

Y5

TGS 813

CO
Y

Y4

Y2

X0 X1 X2 X3 X4

TGS 822

Fig. 3. Graphic approach between the two diagrams

As mentioned above this type of analysis of the information from sensors, although requires a good number of calibration curves, does not require a mathematical representation of these curves by approximating equations etc.

III. The measuring instrument

The approach proposed above, has been developed for the task of automated monitoring the two gases of interest (carbon monoxide and methane) by an accurate stand-alone instrument. The SnO_2 gas sensors have been chosen mainly for the low cost and wide accessibility and acceptability as explained in the second paragraph. The measuring approach is developed under the requirement that it may be implemented by a micro-controller system. Such a configuration based on a small micro-controller, a multi-input A/D converter and a few other peripherals is shown in Fig. 4.

The two sensors are operated with different heating voltages ($V1_{SUPPLY}$ and $V2_{SUPPLY}$) in order to obtain the specific operating conditions as described previously. The excitation signal for each sensor is provided by means of a controlled current source circuit I_{E1} and I_{E2} (one for every sensor) for accurate reading of the resistance variation in the form of voltage variation. These two voltage signals are then fed to the multi-channel A/D converter (12 bits, serial output) along with other signals for monitoring the proper operation of the whole configuration (i.e. sensor supply voltages, etc). It should be noted that although the value of conductance is used in the processing procedure, this configuration provides a voltage proportional to the resistance changes, and then conductance is calculated in the micro processing unit. The inverse procedure where a constant voltage would drive the sensors and would provide a current as the output variable is considered as less accurate solution and consequently is not preferred in this case.

The ATMEL AT90s8515 microcontroller unit is used in the prototype instrument that has been developed and tested successfully. The unit is designed to work as a stand-alone measuring instrument and the primary means of output under typical operating conditions is the display unit (Fig. 4). A serial communication port to a PC is also provided for ease of use during the calibration and testing procedure. All measurements, testing, and parameter settings may be implemented through this port as well.

The whole processing procedure, which has been described above, is absolutely compatible with the capabilities of a microcontroller system with a certain memory backup. Usually the internal memory of the microcontroller is not enough to store the required volume of calibration points. An external memory chip may be easily added, and is required to support the volume of calibration data needed to

achieve a small error figure at the estimated output. From the theoretical diagram of Fig. 3 may be easily result that if the number of curves in each family (or the intersecting points) is limited, then the accuracy of the estimation is also limited. Yet, the measuring instrument may be also realized with no additional (external) memory if the required operating range is limited.
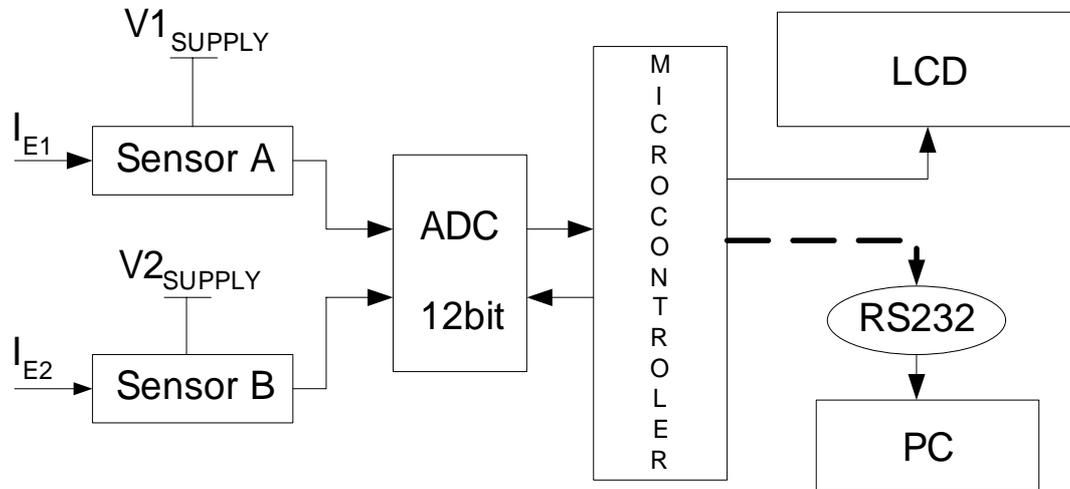

Fig. 4. Configuration of the measuring instrument

For an accurate implementation of the method it is important though, that the slopes of the two families of curves are significantly different. Consequently, the procedure of determining the proper heating voltage value of a gas sensor should be focused on obtaining different sensitivity factors (slopes) for the two sensors. An important advantage of such an approach is that both sensors are working at a constant temperature (different for each one, but constant). Variations of heating voltage which is adopted by other approaches is increasing the measurement error significantly due to the large time constant and the asymmetric behaviour of the sensors. In fact even with constant operating voltage, SnO_2 sensors, which have been tested in our system, are exhibiting a hysteresis loop with slightly different behaviour when the concentration is increased or decreased. Yet, since the operating voltage is constant for each sensor, such phenomena can be compensated by the computerised procedure; in cases where the hysteresis loop is not negligible, the actual measurement system may be programmed to use different processing factors depending on the "direction" of the concentration measurement (upwards or downwards).

The overall error figures of the output values for the concentration of the two gases are in the order of 3%, for a typical experimental test performed at the above mentioned experimental setup. Note that these values are calculated for different points all over the range of the concentration of each one of the two gases, which are quite different in this application. Methane concentration is considered over a wide range of zero to 8000ppm while the other gas (Carbon Monoxide) is limited only up to 1600ppm. Also it should be noted that other issues as the hysteresis loop are not taken into account in these tests. In all cases, our experience based on the multiple experimental measurements performed with the same setup, indicates that the main source of errors is not related to the processing procedure described here, but to the relatively low reputability of the direct sensors readings. Furthermore is interesting to note that this error figure is not shown to diminish, as the measured value is increased (larger concentrations) as might be expected.

IV. Conclusions

The development of a microcontroller-based gas measuring system is presented in this paper. A novel, graphical approach, compatible with microcomputers' capabilities is proposed for accurate extraction of the desired information. Using two commercial SnO_2 sensors, and on the basis of multiple experimental measurements, the proposed method is shown to be capable of estimating the

concentrations of carbon monoxide and methane. The overall measurement error of this method is shown to stay below 3% for all operating range of concentrations of the two gases. Furthermore, there are certain indications that this error is not caused by the processing method, but from the low repeatability of the sensors used.

Acknowledgment

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