Virtual Instrumentation with Mobile Device control for Methane Concentration Measurements

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***Abstract*—This paper presents the design and functionality of a methane (CH_4) concentration measurement system, based on a virtual instrumentation (VI) solution implemented using National Instruments' LabVIEW. It contains a semiconductor type dedicated gas sensor, specific conditioning circuitry and a software program running on a portable computer. An important feature of the proposed implementation is the possibility to transmit calculation results and receive control commands from a mobile phone with internet connectivity. Other features include data logging of concentration parameters and statistical calculations. The instrumentation represents a cost effective solution due to software/hardware adaptability and can be easily extended for monitoring other gases. Experimental results which illustrate the operation of the system in CH_4 contaminated environments are also presented.**

Keywords-LabVIEW; Mobile Phone Control; Gas Sensor; Virtual Instrumentation; Methane Concentration.

I. INTRODUCTION

The use of semiconductor type gas sensors for applications which investigate ambient air pollution levels is a common approach due to several reasons. These sensors combine high sensitivity to target gases, low power consumption, long life, straightforward installation and low cost. Together with an appropriate software application, one can develop a measurement system which can be adapted to monitor one or several gases [1, 2, 3].

The use of combustible gases within industrial and civil buildings represents a permanent explosion and/or fire potential danger. Such disasters happen due to gas accumulations caused by improper device operation or leakage. When concentrations of such gases reach the LEL (Lower Explosion Limit) values, in contact with the air and a fire source (spark, high surface temperature), they can cause explosions which may lead to life and material loss.

Mobile phone applications offer new possibilities of effective remote control and monitoring. They are becoming more reliable, interesting and attractive. Extensive development of such solutions for domains like city car parking, power plant monitoring, SMS (Short Message Service) if monitored parameters are outside allowed limits, SMTP e-mailing or medical condition monitoring, is a current concern. Instrumentation companies offer software and hardware packages for development of mobile solutions for hand-held devices and smart-phones.

Wen et al. [4] describes an interesting tele-monitoring application which records ECG signals, processes the waveforms and sends SMS (Short Message Service) messages to authorized mobile phones if anomalies are automatically detected. The communication between the elements of this system is provided by a Web Server and the TCP/IP protocol.

Another implementation which uses a mobile device for transmission of SMS warnings with the purpose of alerting farmers is proposed by Aziz et al. [17]. Recorded temperature data is processed and with the help of a GSM modem, alerts are sent to mobile phones in case levels exceed accepted limits.

This paper presents a virtual instrumentation which was designed for CH_4 concentration calculation and monitoring. The concept of VI involves a software and hardware ensemble which has the purpose of replacing a stand-alone, dedicated device. The main advantage of this approach is the possibility to exploit the calculus power and performances of the PC on which the software component runs.

Technological innovations together with customer needs for increased functionality in smaller dimensions devices, have caused the spread of VI in domains like: health and medicine, environmental monitoring, remote monitoring, structural investigations, clean energy production, data transmission, industrial control, education, robotics and/or automation.

In related literature, the use of VI is demonstrated by Farhey in [5]. The author presents a solution for monitoring the structure of a bridge. Recorded data are used for evaluating the condition of the construction. The system includes sensors, wireless transmitters and a user-friendly graphical user interface.

Rana and Khan [6] present the complete implementation of a Digital Oscilloscope which uses a NI PCI-6035E card and LabVIEW. This tool is used to study complex signals and includes algorithms for frequency and time domains analysis.

In order to extend the mobility of our application, access to measurement results and program control is available by the use of a web browser on a mobile phone. The user can also choose to store data values and calculations results on

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the host computer. These options turn the proposed instrumentation into a portable solution which is both reliable, low cost and can be easily adapted to perform different analysis on the measured data [4, 6].

There are two important components which constitute the CH_4 monitoring system.

The hardware includes the TGS2611-C00 methane gas sensor. This sensor satisfies the performance requirements of the UL1484 and EN50194 standards. Specific applications are domestic gas alarms, portable gas detectors or gas leak detectors for gas appliances. It is part of a measurement circuit connected through a data acquisition device to a personal computer. The sensor's analog output is sampled and transmitted to a computer program using USB connectivity. In manufacturer specifications, the use of this sensor is restricted to detecting if the CH_4 concentration exceeds the accepted limit.

The software component uses state-machine architecture for both, control of the measurement circuit and data processing requirements [7, 8]. It was implemented using LabVIEW development environment with the Database Connectivity Toolset and the NI DAQ MX drivers. NI Multisim 11.0 was used for circuit design and analysis. PHP 5.3.5 and MySQL 5.1.54 (embedded in EasyPHP 5.3.5.0) were used for data transmission and application control. Line style flash charts designed by AmCharts were included in the mobile phone user interface. The LabVIEW Web Publishing Tool was used for creating the HTML document which can be accessed using a notebook. In such cases, one has to check if the RunTime Engine software component is installed on the remote computer [10, 11].

Section 2 presents the CH_4 concentration measurement system. This section includes a description of a proposed empirical algorithm for methane concentration calculation. The virtual instrumentation hardware and the software components are discussed. Section 3 presents relevant experimental results. Conclusions regarding both experimental results and future development of the application are mentioned in the final section.

II. METHANE CONCENTRATION MEASUREMENT SYSTEM

An overview of the CH_4 measurement system is presented in Fig. 1. The functionality was tested under laboratory conditions. The measurement circuit contains the CH_4 gas sensor and the proper signal conditioning. This circuit was placed in a laboratory where we could safely feed target gas concentrations to the sensor. Using a data acquisition device (NI USB-6251) as interface between the circuit and the computer running the acquisition software, data is sampled and analyzed. If the user chooses to remotely view the calculation results and control the application, an option for Internet Connectivity is available. In this scenario, raw measured data and calculation results are sent to a remote Web Server with SQL and PHP support. Remote access to all available information requires authentication (using a username and a password) and can be obtained via an html page which resides on the Web Server. For this case we used a Mobile Phone and a Notebook to both view data and control the measurement circuit.

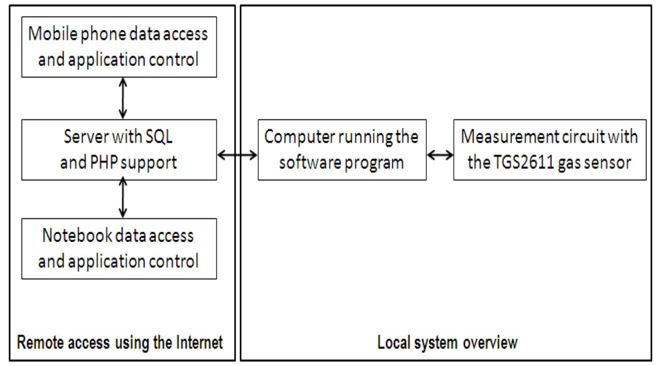

Figure 1. Overview of the methane concentration measurement system.

The TGS2611-C00 semiconductor type gas sensor is the core of the application. It provides high sensitivity to methane and low power consumption. For this particular application, the sensor was used with the pre-calibrated NGM2611-C13 module. This module includes temperature compensation and meets RoHS regulations. Variations of the electrical parameters for the TGS2611-C00 sensing element are very consistent with concentrations of CH_4 in the surrounding environment [3, 9, 15].

Fig. 2 shows the logarithmic representation for the sensitivity characteristics of the TGS2611-C00 under standard test conditions (manufacturer specifications). One can notice that the sensor internal resistance ratio (R_s/R_o), decreases as target gas concentration increases.

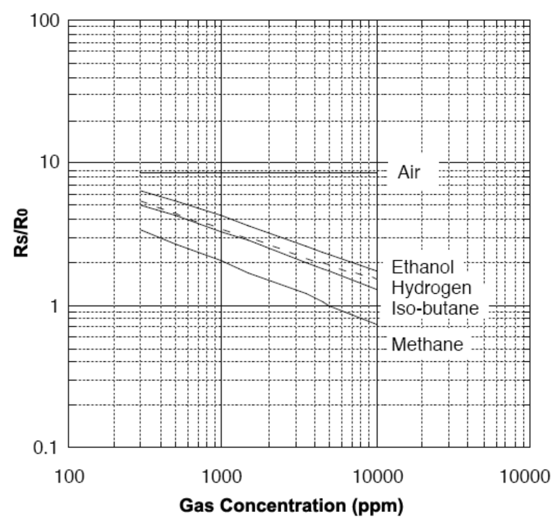

Figure 2. Gas sensor TGS2611 description: sensitivity characteristics.

In the case of methane, the sensitivity characteristics show that R_0 is equal to the sensor resistance R_s when the concentration is 5000 ppm. The recommended concentration values domain is 300 ppm to 10000 ppm. These characteristics are specific for every sensor type. Therefore, one should pay attention to the producer code for each device (#11 in our case) because the load resistor should be chosen in accordance.

The accepted Lower Explosion Limit (LEL) value is 50000 ppm. For this particular case, the NGM2611-C13 module was calibrated to generate an alarm signal when the gas concentration reaches 5000 ppm (or 10%LEL). In practice, this limit is variable due to factors like test conditions tolerances, heat generation inside the sensor enclosure or humidity. If the circuit is operating at recommended parameters, the interval for the accepted alarm limit value is 5%LEL to 20%LEL.

Fig. 3 shows the NGM2611-C13 basic circuit diagram.

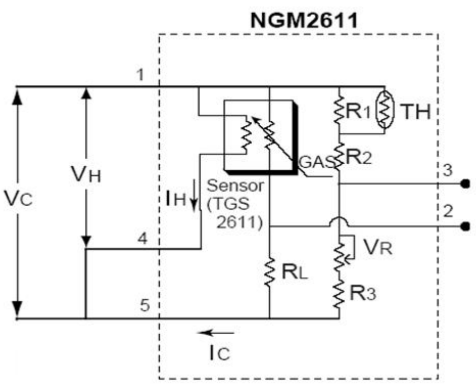

Figure 3. Calibrated module basic diagram.

The operation of the implemented measurement circuit requires a current I_C = 90 mA and a steady V_C = 5 V voltage. As the current flows through the heater, the sensing element is heated and starts to react to the target gas. The voltage divider which contains the sensing element and R_L outputs at pin number 2 an electrical potential which increases with the gas concentration. At the same time, the voltage divider composed of R_1, R_{TH}, R_2, R_3 and R_{VR} (potentiometer resistance) sets on pin 3 the alarm signal threshold which in this case is approximately V_{Alarm} = 2.5 V (alarm threshold). When the voltage on pin 2 exceeds V_{Alarm} the alarm signal is triggered. In this way one can detect if the CH_4 concentration is above the established limit.

A. An empirical relation for concentration calculation

As specified by the manufacturer, the common use of the TGS2611-C00 is for detecting if the CH_4 concentration level exceeds the 5000 ppm limit. This paper extends the application range of the TGS2611-C00 sensor to continuous monitoring of methane concentration. Thus, based on the sensitivity characteristics presented in Fig. 2, an empirical relation between the CH_4 concentration value and the sensor's output voltage was determined. As a first step, the empirical relation (1), between the sensor's internal resistance ratio R_s/R_o and the methane concentration C, was found.

$$\frac{R_s}{R_0} = \frac{D}{C^k},\ for\ 300\,ppm \le C \le 10000\,ppm \tag{1}$$

The values of the empirical constants are: D = 46.2 and k = 0.45. Fig. 4 shows two graphical representations of the internal resistance ratio (R_s/R_o) versus methane concentration. The logarithmic representation (bottom) is consistent with the appropriate sensitivity characteristic presented in Fig. 2. This means that the constants D and k were accurately determined.

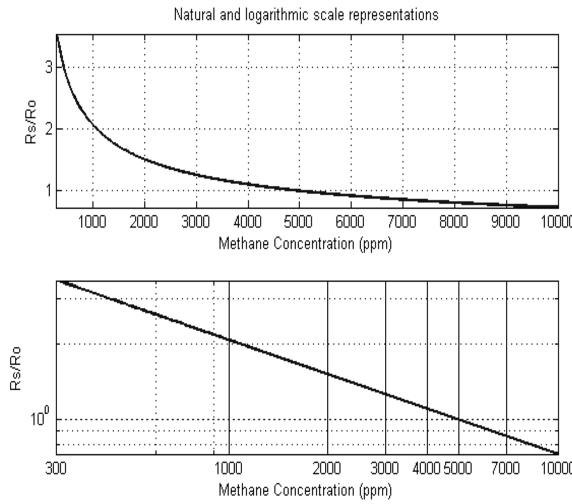

Figure 4. Resistivity ratio versus. methane concentration: natural (upper) and logarithmic scale representation (bottom).

From Fig. 2, the voltage V_{RL} measured on the load resistor R_L can be expressed as:

$$V_{RL} = \frac{V_C}{R_S + R_L} \cdot R_L \tag{2}$$

For an output voltage $V_{RL} = V_C/2$ = 2.5 V corresponding to a CH_4 concentration C = 5000 ppm, it follows that R_L = R_s at C = 5000 ppm, or R_L = R_0. Thus, (2) can be also written as:

$$\frac{V_C}{V_{RL}} = \frac{R_0 + R_S}{R_0} = 1 + \frac{R_S}{R_0} \tag{3}$$

Combining (1) and (3), one can determine the empirical relation between the measured output voltage and the methane concentration, C :

$$V_{RL} = \frac{V_C}{1 + 46.2 \cdot C^{-0.45}},\ for\ 300\,ppm \le C \le 10000\,ppm \tag{4}$$

Finally, from equation (4) one can express the methane concentration as a function of the measured output voltage.

$$C = \left[46.2 \cdot \frac{V_{RL}}{V_C - V_{RL}}\right]^{\frac{1}{0.45}} \tag{5}$$

Fig. 5 shows the natural scale representation of the CH_4 concentration values as a function of measured sensor output voltage.

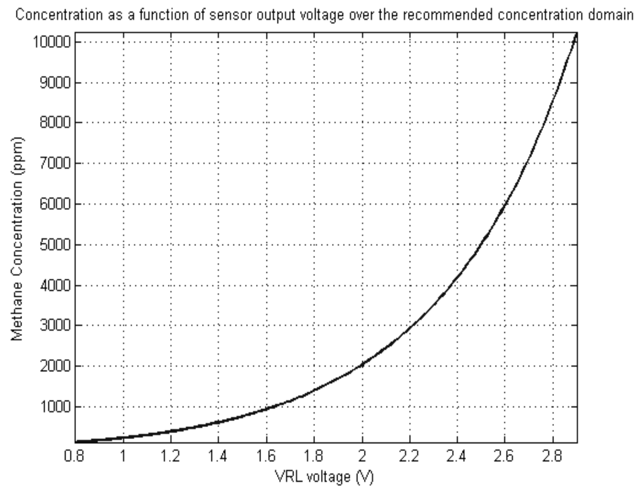

Figure 5. Methane concentration versus sensor output voltage.

B. *Virtual instrumentation hardware*

For this particular application, the data acquisition device must provide 2 analog input lines and the 5 V power line. The multifunction NI USB-6251 device offers the required features. A connector with screw terminals (CB-68LPR) was used to easily access individual signals. Highly selective response to CH_4 can be obtained by eliminating transients by using a filtering material or an appropriate delaying circuit. The latter solution was chosen for this particular implementation. The sensor's response to the target gas stabilizes within minutes (2.5 minutes according to manufacturer specifications), depending on how long it has been inactive. A warm-up alarm prevention RC circuit was implemented with the purpose of delaying the sensor response after power-up. Only when the acquired data is stationary can the correct concentration be calculated [12, 13].

Target gas concentration may fluctuate around the 10%LEL level. A circuit for prevention of disturbing intermittent alarming was implemented. In this way a range for the alarming threshold was created. The alarm is triggered when the sensor voltage exceeds the upper range and lasts until the voltage drops below the lower range.

A final RC circuit was implemented with the purpose of eliminating false alarms caused by the sensor’s reaction to transient interference gases such as alcohol vapors. The recommended timing for the alarm delay is 15 s.

The component values for the TGS2611-C00 sensor were set in order to simulate the case when the R_S value corresponds to a 5000 ppm gas concentration. The values for the NGM2611-C13 module components are set according to specific measurements. The Data Acquisition part was implemented using the MCP601 amplifier as a voltage follower. In this way the sensor voltage is transferred to an input line of the NI USB-6251. The conditioning circuits were designed using LM339 comparators. A single LM339 chip was used in the actual circuit since it contains four separate comparators.

C. *Virtual instrumentation software*

The main features of the proposed instrumentation are:

- The possibility to change the acquisition sampling time from 1 second to 5 seconds. The user can stop the acquisition and resume it without losing the displayed data.
- For ulterior processing, measurement data and calculations results can be saved in a text file on the host computer.
- The user can activate the option for sending data to the server and for allowing remote application control from the mobile phone.
- Calculations are performed and displayed with each measurement. Methane concentration calculated in ppm and percentage, real-time voltage values for the sensor signal and the alarm limit (V_{Alarm}). The concentration values are obtained based on the linearity of the sensitivity characteristics. The voltage values can be studied in order to see if the circuitry is functioning at correct parameters.
- Error messages are displayed if the server or the input lines of the NI USB-6251 cannot be accessed.
- Time domain representations for the sensor output voltage, alarm limit voltage and a running average of the last 4 measured sensor voltage values are presented.

Some practical applications in which these features can be used are gas concentration monitoring in residential buildings, tunnels or underground parking. Also, collected data can be used for statistical calculations which are used for long term studies of concentration evolution.

Fig. 6 presents the basic execution diagram of the software component.

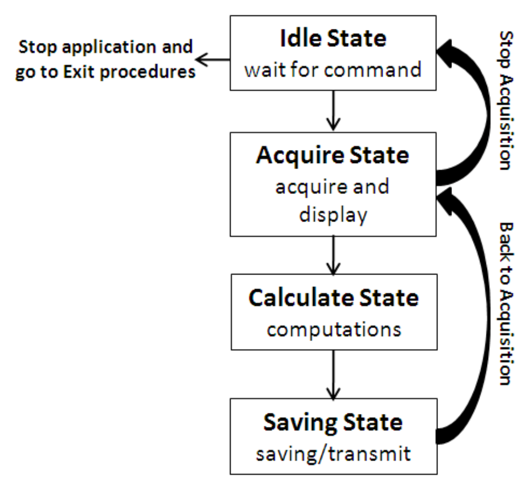

Figure 6. Basic software execution diagram.

The software component was developed using the JKI software add-on state-machine architecture. The advantage of using the JKI state-machine is that starting from a well

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defined structure, new states for Acquiring Data, Calculations and Data Saving were introduced. We adapted the existing Data Initialize/CleanUp states according to particular needs. Another important issue is the functionality of the front panel buttons when the application is running. Property nodes which disable and enable the front panel buttons can be used as the code execution flows through the states. In this way one can avoid the situation of front panel freezing when the application is in the Acquiring Data state and the user presses the Exit button.

Fig. 7 shows the front panel of the virtual instrument. A short period when the gas concentration exceeds the allowed limit can be noticed on the voltage waveform graph. Operation settings, calculation results and functionality errors indicators are included.

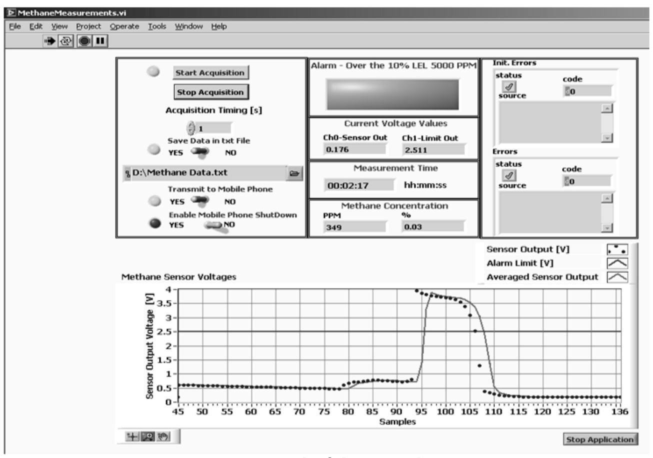

Figure 7. Front panel of the virtual instrument.

The Database Connectivity Toolset is used to transmit and receive information to/from a server from/to the application running on the software program. Before running the program, an UDL (Universal Data Link) file was created in order to define the communication with the server. This file is used by the DB Tools Open Connection function from the Database Connectivity Toolset. Once the remote connection is successful, the program will be able to transmit and receive data over the Internet. Two tables are used for this particular application. One is used for storage of current measurement data, the other is used for remote commands sent from the mobile phone to the instrumentation [14, 16].

If new measurement data is available on the server, a remote user can connect to the database and view the results. The same server hosts the PHP files which can be accessed using the mobile phone browser. Furthermore, if the remote user works with a portable computer, two connectivity possibilities are available: either by using the PHP files on the server or by using the HTML document created with the LabVIEW Web Publishing Tool on the host computer. The client computer must have the RunTime Engine software component installed. This allows complete control of the main application, if requested by the client computer and granted by the host computer.

When accessing the PHP file on the server, an AmCharts' Flash line graph is loaded. Using the same PHP script, data values (last 12 recorded) and calculation results are read from the database and displayed on the mobile phone screen. If needed, the mobile phone user can stop the main application.

Fig. 8 shows the remote operation of the measurement system using a client notebook (upper image) and the mobile phone (bottom image). In both cases one can notice that the measurement system senses the presence of a higher methane concentration.

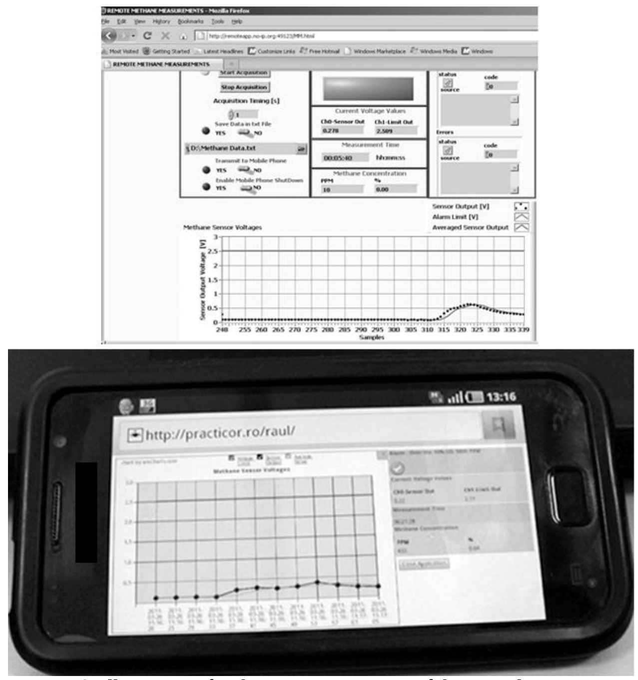

Figure 8. Illustrations for the remote operation of the virtual instrument.

III. Experimental Results

Confirmation of the application's functionality was carried out in laboratory conditions. The NGM2611-C13 module was exposed to concentrations which were above and below the accepted LEL value.

Table 1 presents measurement results recorded several minutes after the sensor response has settled, including the short time period when a high CH_4 concentration was recorded. Immediate reaction to the presence of CH_4 inside the sensor's enclosure can be noticed. After the target gas slowly exits, the sensor's response falls to initial values. The values presented in the table were obtained using (5). Since this relation is considered accurate over the 300 ppm to 10000 ppm domain, one can notice that the valid calculations are presented in bold.

TABLE I. Recorded Measurement Values When the Sensor Was Exposed to a Sudden High Methane Concentration

Sensor Output (V)	Alarm Limit (V)	PPM (rounded)	Alarm
1.23	**2.51**	**413**	**0**
1.36	**2.51**	**558**	**0**
1.49	**2.51**	**740**	**0**

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1.51	**2.51**	**772**	**0**
1.49	**2.51**	**740**	**0**
1.59	**2.51**	**912**	**0**
1.62	**2.51**	**969**	**0**
1.54	**2.51**	**822**	**0**
1.41	**2.51**	**623**	**0**
1.73	**2.51**	**1207**	**0**
1.84	**2.51**	**1493**	**0**
1.87	**2.51**	**1581**	**0**
1.92	**2.51**	**1737**	**0**
1.96	**2.51**	**1872**	**0**
2.04	**2.51**	**2171**	**0**
2.11	**2.51**	**2467**	**0**
2.17	**2.51**	**2751**	**0**
2.28	**2.51**	**3353**	**0**
2.35	**2.51**	**3799**	**0**
2.41	**2.51**	**4227**	**0**
2.48	**2.51**	**4787**	**0**
2.53	**2.51**	**5232**	**1**
2.58	**2.51**	**5718**	**1**
2.61	**2.51**	**6031**	**1**
2.68	**2.51**	**6833**	**1**
2.72	**2.51**	**7339**	**1**
2.71	**2.51**	**7209**	**1**
2.65	**2.51**	**6477**	**1**
2.61	**2.51**	**6031**	**1**
2.54	**2.51**	**5325**	**1**
2.48	**2.51**	**4787**	**0**
2.41	**2.51**	**4227**	**0**
2.24	**2.51**	**3121**	**0**

Fig. 9 presents the graphical representation of the recorded data presented in Table I. The evolution of the recorded values is presented both as sensor output voltage (using the -*- format) and as CH_4 calculated concentrations (using the -□- format). The voltage limitation of 2.51 V is presented as a dashed line. The Alarm region indicates that the calculated concentration exceeded the 5000 ppm limitation.

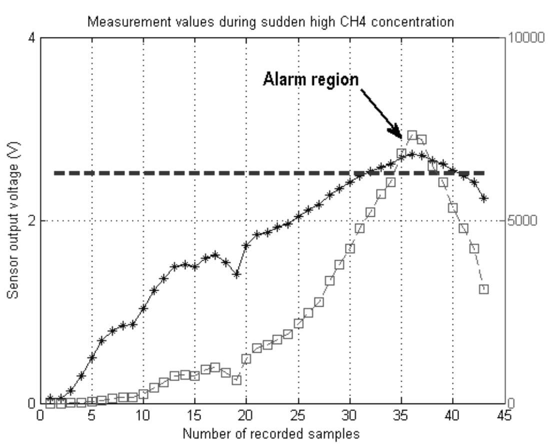

Figure 9. Representation of recorded data and concentration calculations.

IV. CONCLUSIONS

In this paper, the design and implementation of a virtual instrumentation solution for monitoring CH_4 concentrations was presented. The application uses the TGS2611-C00 sensor, the NI USB-6251 data acquisition device and the LabVIEW 2009 development environment.

An original and state of the art feature of the proposed system is the possibility to remotely view measurement results and control the operation using a mobile phone with Internet connectivity and Flash script capabilities. Remote access from a client computer, using the LabVIEW Web Publishing Tool, is also possible.

Experimental results showed that the proposed system's response to the sudden exposure to a high concentration was accurate and fast. Remote monitoring from a mobile phone and a client notebook were successful. This determined the conclusion that the proposed instrumentation has been properly designed and implemented. An empirical formula for concentration calculation was proposed in (5) and was implemented in the software component.

As further development, our goal is to test the precision with which CH_4 concentrations are determined. This can be done by taking measurements in spaces where a predetermined methane concentration is inserted. Furthermore, new options for controlling the instrument using the mobile phone are needed. This will assure complete operation from distance without the imperative need of a computer.

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