A new approach for carbon monoxide measurement using virtual instrumentation

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Abstract: - The measurement of carbon monoxide (CO) concentration is an integral part in a large number of practical applications that monitor pollution levels. One area of applicability is the determination of CO concentration produced by car engine’s emissions. Tests are typically performed using dedicated stand-alone modular specialized analyzers, working on standardized methods that provide information concerning the flue gas composition, including CO. This paper presents an alternative solution for CO monitoring, based on virtual instrumentation. The application offers accurate CO concentration measurement results, data logging options, statistical calculations and remote access. In order to verify the functionality of the application, comparative tests were performed, at a car service company.

Key-Words: - Carbon Monoxide Concentration, Gas Sensor, LabVIEW, Data Acquisition, Remote Monitoring.

1 Introduction

Carbon monoxide, the target gas in the presented application, is a colorless, odorless, tasteless and highly toxic substance. CO is not only a pollutant but also its presence is a proof of uncompleted combustion, generating efficiency losses and thus higher fuel consumption and specific costs. Its concentration is similar to that of most gases and can be measured with adequate sensors [1], [7], [8]. Measurements of CO concentration can be found in diverse domains including the study of gases which are emitted by car engines. Technical validation for engine functionality is not approved, if the CO concentration in flue gases exceeds established limits (by law). In this paper, a solid-state, high sensitivity CO – TGS2442 sensor was used. It works with the measurement system illustrated in Fig.1.

![Fig.1. CO measurement system overview](image)

The sensor is part of a measurement circuit connected through a data acquisition device to a personal computer. Digital signals are generated in order to properly heat the TGS2442 sensor before making a measurement. Its analog output is sampled and used to calculate the CO concentration [4], [7]. Furthermore, the software programs perform data logging by saving relevant information in a text file and allow remote access to the virtual instrument's user panel. A graphical display of the calculated CO concentration allows the user to view the time evolution. Instantaneous measured values and the mean over the last five measurements are shown. Control warnings point out if the sensor works at the required parameters.

The virtual instrumentation hardware and software components are detailed in the following two sections. The author's conclusions, regarding both the experimental results and the development potential of the application, are mentioned in the final section.

2 Carbon Monoxide Measurement Method

The solid state gas sensor used to detect the concentration of carbon monoxide provides the core of the application. The TGS2442 sensor's functioning principle is based on the sensibility of some metal oxides to different gases. For the TGS2442, the tin dioxide SnO2 reacts with carbon monoxide molecules CO (in the presence of oxygen O2) and releases free electrons. The electrons increase the conductivity, and therefore determine the decrease of the internal resistance [7].
The sensor includes a heater that accelerates the chemical reaction and maintains an adequate temperature inside the enclosure. Its basic structure, measuring circuit and operation signals diagram can be seen in Fig.2.

![Fig.2. TGS2442 CO sensor basic structure and operation signals](image)

The software application component was built with virtual instruments (VIs), programmed in National Instruments LabVIEW development environment. The data acquisition device required by this particular application must provide two analog input, three digital output lines and a digital trigger for analog acquisition. The NI USB-6251 data acquisition device provides the required features. The sensor is heated through digital pulses programmed on the computer's virtual instruments and generated by the NI USB-6251. The sensor’s output is measured and processed by a second virtual instrument that determines the concentration of carbon monoxide according to (1)

\[
C = \frac{V_{1\text{ref}} \cdot (5 - V_1)}{V_1 \cdot (5 - V_{1\text{ref}}) \cdot K_{\text{temp}}}^{1/\alpha}
\]

where, \(V_{1\text{ref}}\) is the value of \(V_1\) at a known CO concentration (typically 100ppm), \(K_{\text{temp}}\) is the coefficient for temperature compensation and \(\alpha\), a measure of the slope in the sensor's characteristic [7]. The \(V_{1\text{ref}}\) and the \(\alpha\) parameters are constant and can be measured for every sensor. The \(K_{\text{temp}}\) parameter is dependent with the temperature. The manufacturer provides \(K_{\text{temp}}\) coefficient values. The application allows the user to select a value for the ambient temperature and the software will automatically select the corresponding \(K_{\text{temp}}\) value.

As indicated in Fig.2, one measurement cycle lasts 1 s. The heater requires a 4.8 V pulse of 986 ms width. The sensing element requires two 4.8 V pulses of 995 ms width, with a 1 Hz frequency. These digital signals are to be synchronized. The electrical current through the heater must be high enough during the “Low” Pulse state (200 mA according to the sensor’s documentation). The sensor's response stabilizes within several minutes, depending on how long it has been inactive. In this application, the stabilizing time ranged from 10 to 20 minutes.

Since the role of the digital signals is to heat the sensor, they ultimately allow for an accurate reading of \(V_1\), the voltage acquired at the midpoint of the RL1 pulse on the S-in line. The accuracy of the reading depends on the accuracy of the timing between the voltage acquisition and the digital signals. In order to test the precision of the timing values, the signals were measured using conventional oscilloscopes, with the results illustrated in Fig.3. They correspond to the requirements presented in Fig.2.

![Fig.3. The Pulse and RL1 signals tested with the oscilloscope](image)

3 Virtual Instrumentation Hardware

The hardware generates the digital signals programmed through software and receives analog data obtained from the CO measurement circuit. A total of three digital lines from Port0 (P0.0 through P0.2) and two analog input lines (AI0 and AI1) are reserved by the application. These lines, together with the power lines are supplied by the data acquisition device.

In the actual circuit configuration, for easier line access, a connector with 1.25 screw terminals (CB-68LPR) was used to access individual signals. For example, the digital signal used to trigger the acquisition was connected through wires both to the sensor circuit and to the trigger input pin, using the screw terminal connector block. Fig.4 illustrates the structure of the actual measurement circuit (schematic and experimental setup).

![Fig.4. CO measurement circuit](image)
As specified, the sensor needs both digital output signals and analog input lines in order to measure CO concentration. The NI USB-6251 acquires analog data on maximum 16 input channels, with up to 1.25 mega samples per second and generates both digital and analog signals, on three digital ports and two 16-bit analog output lines. Frequency and start time for analog acquisition can be supplied either by an internal clock (through software) or by an external trigger signal. For example, if the trigger is a digital signal, the acquisition can be initiated by its falling slope, as is the case in this application.

4 Software Functionality

As mentioned before, the tasks that need to be accomplished by the system are to generate the digital signals required by the sensor to function and to acquire the analog value of $V_1$ [7]. Signal's generation and acquisition needs to be precisely timed for optimum detection CO concentration calculations. An added feature allows remote access through the Internet. All the tasks are performed through virtual instruments which run in parallel. This parallel execution is dependent on the operating system. Since the timing requirements of this application demanded synchronization at a millisecond level, several functionality tests were performed using oscilloscopes and DMMs. In this way functionality and timing were validated. The LabVIEW programming environment allows for tasks to be distributed to available processors and processor cores, and the NI-DAQmx driver further enables parallel execution [2].

The first VI generates the three digital signals (described in Fig.2), out of which the falling slope of Pulse will be used to trigger the analog acquisition of $V_1$. During the four states identified in Fig.2, all the signals have constant values that are fed to the digital output lines of the hardware device as a constant boolean array. A wait function then determines the number of milliseconds for each state. These operations are performed continuously in a loop, whose execution can be ended by the user. The second VI created for this application performs the analog acquisition and all the required calculations. This VI is triggered by the digital Pulse and executes in a loop, every 3 seconds. The results of this acquisition are two series of 1000 samples, one from the sensor's S-in line and one from the heater's H-in line. By extracting the values for $V_1$, $V_2$, $V_5$ and $V_6$ from the series of samples, the program can calculate the CO concentration and determine if the sensor is functioning correctly. Fig.5 presents the block diagram of the VI which generates the signals. Fig.6 presents the front panel of the VI which acquires data and performs the concentration calculations.

The indicators make up most of the front panel and display information on the sensor's output, functioning and previous measurements. Numerical indicators show the values for the calculated CO concentration, $V_2$, $V_5$ and $V_6$ voltages and the time elapsed since the measurement began. The minimum and maximum values of the measured concentrations are also displayed in a numerical indicator, in order to put current values into perspective. The remaining two indicators are a graph, “Line Voltage”, and a chart, “CO Concentration”. The “Line Voltage” contains all the voltage samples acquired in the previous second, namely two plots representing the two lines S-in and H-in. The “CO Concentration” chart shows the most recent 100 concentration values, adding a moving average as a second plot for a smoother display.

The values of $V_2$, $V_5$ and $V_6$ voltages are extracted from the two series of samples resulted from the S-in and H-in lines. $V_1$, along with the $K_{temp}$ coefficient, is used to calculate the CO concentration, immediately displayed on the front panel, in the numerical indicator and on the chart. Four previous values of the concentration, obtained through shift registers, are added to the current value in order to calculate the moving average, found on the chart indicator. The current value of the concentration is further used to update minimum and maximum value indicators, and to be concatenated into a string as part of the logged data.

For saving the measurement data, the text file format was chosen. Every line in the file represents one measurement and is composed of the current date and time, the $V_1$ voltage value, the value of the current CO
concentration and error details (if they exist). An error is considered the sensor malfunction and is indicated by the values of $V_2$, $V_5$ and $V_6$. These values indicate an error if they exceed the limits defined within the application and presented in [7]. If the sensor is not functioning correctly for more than 150 consecutive seconds (50 measurement cycles), the errors are no longer logged. Another way for suspending data logging is for the user to select that option on the instrument’s front panel.

Fig. 7 presents the general execution schematic of the CO measurement program.

![Fig. 7. Execution of CO measurement VI](image)

5 Experimental Results

The confirmation of the application functionality was performed at an authorized car service company. In this way all measurements were compared with official, attested and legal results provided by the car service company. Some results obtained for the case of a car with an engine running on petrol are presented below.

For exhaust gases parameters measurements, the car service company uses a Sun - MGA 1500 stand-alone testing device. A gas probe was inserted in the exhaust pipe and the device indicated the concentrations. Fig. 8 presents the probe and the Sun - MGA 1500 taking simultaneously and on line measurement.

![Fig. 8. Exhaust parameters measurement with the Sun – MGA 1500](image)

The specialized device provides values for the $CO_2$, HC, $O_2$, CO, engine rotations and oil temperature. The value of interest for our application was only that of the carbon monoxide. For the car on which the tests were run, the indicated value of interest was 0.01% CO concentration. This is the best possible value to be obtained and is explained by the fact that the car experienced an engine revision up to date. Unaccepted levels for CO concentration start from 0.30%, if the acceleration pedal is not pressed or 0.20% with the acceleration pedal pressed. These values refer to an engine with an Euro 4 catalyzer. The tests which were performed with the virtual instrumentation application covered the case of the engine running without the acceleration pedal being pressed.

Exhaust gases from the same car were supplied to the sensor. As the application was running, the sensor’s output CO concentration value began a steady rise. This was expected since it requires a settling time of several minutes. Fig. 9 presents the experimental setup using the virtual instrumentation.

![Fig. 9. CO measurement experimental setup](image)

Fig. 10 presents the settling of the CO indication towards the correct values. The dots on the graph indicate instantaneous values. The continuous line indicates the moving average of the calculated values. Fig. 11 presents the test parameters for the sensor and the heater.

![Fig. 10. CO concentration values](image)

![Fig. 11. Test parameters for the TGS2442 sensor](image)

After several minutes of functioning the calculated CO concentration values started to enter into a constant trend with limits ranging from 80ppm to 90ppm. By transformation, these values indicate a concentration...
level with the upper limit of 0.009% CO concentration. Since the first two decimals indicated the same values (several measurements were taken) as the Sun - MGA 1500 dedicated device, the functionality of the application was considered valid. In all cases both the sensor and the heater tests indicated no sign of malfunctioning. Voltages and calculated concentrations were logged in order to use them for further analysis.

6 Conclusions
In this paper, a virtual instrumentation solution for measuring and calculating the CO concentration from car engines exhaust gases was presented. The application uses the TGS2442 sensor, the NI USB-6251 data acquisition device and the National Instruments LabVIEW development environment. A dedicated circuit for the sensor was implemented and was controlled by a series of digital signals. In order to verify the proper functionality of the TGS2442 sensor, three voltage values were sampled from the dedicated circuit. Another voltage value was sampled and used for CO concentration calculations according to the appropriate formula.

It has been shown that the results provided by the application were compared to the results provided by a dedicated professional equipment (Sun - MGA 1500). Insignificant differences between the results obtained by classic and virtual methods were attested. This determines the conclusion that the virtual instrumentation is correctly functioning and has been properly designed. However, one notices that the use of this particular virtual instrumentation means that there will be several minutes of incorrect measurements in the beginning. This fact is due to the settling time of the TGS2442 sensor. Further improvements require the use of a thermocouple for automatic temperature coefficient determination and testing the instrumentation using different CO known concentrations.

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