Acquisition and Calibration Interface for Gas Sensors

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***Abstract*— Calibration is the process of obtaining the most accurate sensor data. The MQ gases sensors are produced to measure different types of gas at the same time but the datasheet formula for calibration are poor. To solve this problem, one thing to do is to know what it is the measured substance and to identify formula. The article presents a method of calibrating gas sensors using LabView. The acquisition system consists in a sensors network, which transmit data to an acquisition board and to the computer. The identification of the calibration equation is used to calibrate gas sensors. The methods used to identify the calibration are linear regression and samples compare.**

Keywords — interface, calibration, gas sensors, mathematic equation, linear regression

I. Introduction

The gas sensors, as application in intelligent system, are used in many domains to identified air proprieties. The methods of sensors interconnection and communications are dedicated to the application. The reason to study the calibration gas sensors is the error occurred after the data acquisition. Usually the calibration formula is implemented on the acquisition board. In this project, we implement the gas sensors calibration using LabView interface (Fig.1) [1, 2, and 3]. The gases values data are collected with Arduino Mega 2560 board. To receive the data on the computer using LabView 2013, we tested two methods of data acquisition. One of them is using LIFA Base soft for Arduino and Arduino Toolkit Box. This method is limited at the sensors subVi's, so we use the VISA card virtual instrument.

II. The Gas sensors System Description

A. The circuit description

The gases sensors used in the project are in MQ family. We tested some gases sensors, which have different characteristics.

The aim of the project is to acquire the gases values data in the inaccessible places like refrigerator, little places, tube or under vacuum [4, 5, and 6]. The project sensors circuit connected to Arduino Mega 2560 communicates with computer using LabView interface, wireless using XBee S1 modules. In this way, the signal can be sent without constraints like cable USB connection or cable length.

The circuit presented in Fig.1 has the following components connected to Arduino: XBee S1, MQ sensor, DHT22 a digital humidity and temperature sensor, and Bosch Sensortec BME680 An environment sensor for gas, humidity, temperature and pressure detection. The circuit is installed in two dosing boxes, Arduino Mega 2560 one has, hermetically closed and thermally insulated, to protect the microcontroller at negative temperatures and against humidity.

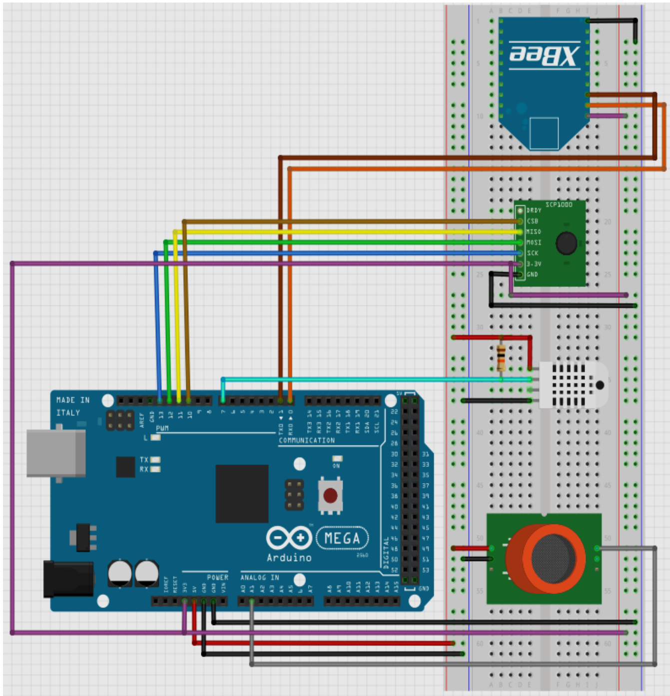
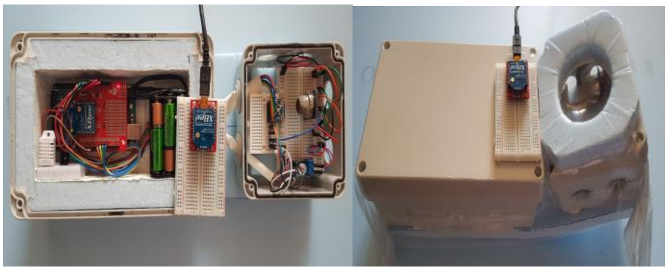


Fig. 1. The block diagram of the sensor connection to Arduino

The DHT22 sensor is designed to monitor the temperature and humidity of the microcontroller's protection box (Fig.2).



a) b)

Fig.2. The acquisition circuit box open a) and in vacuum b)

The assembly is powered at 9V DC from a battery pack

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III. Sensors Calibration

MQ sensors are most used in applications due to their low price and reasonably good lifespan and sensitivity characteristics. It is commercially available in a wide variety of models. The use of a metal oxide semiconductor as a gas sensor was originally proposed by Seiyama in 1962 [7], and since then there are many gas detection applications. The detection mechanism involved in the MOS sensors is well known and some theories have been presented in [8]. One of the earliest empirical mathematical expressions was given by Clifford and Tuma [9, 10].

In the calibration process, we use a voltage sensor to adapt a voltage result of gas sensor.
The first formula is give [11]. It is show as the formula of MOS sensors is unliner with gas concentration (1):

$$R/R\_0 = [\![(1+ k\_gas\ C\_gas)]\!]\ \hat{}(-\beta) \qquad (1)$$

Where R is the sensor resistance, R_0 is the sensor resistance in air, C_{gas} the concentration of gas used, β is the low of characteristic power of sensor, k_{gas} depind of gas. The formula is a power function with negative exponent as:

$$y = ax^b\ , b\ < o \qquad (2)$$

We solve the equation using the nonlinear regression equation using the formula:

$$ppm = a\left(\frac{R_s}{R_0}\right)^b \qquad (3)$$

$$\log ppm = \ \log a + b \log\left(\frac{R_s}{R_0}\right) \qquad (4)$$

$$ppm = \ 10^{\log a + b\log\left(\frac{R_s}{R_0}\right)} \qquad (5)$$

In the datasheet, there is not formula for each gas type of MQ sensors. Using the datasheet graphic, we can extract the formula of gas. For example, we use the MQ2 sensor to extract the points on the graph (H_2ppm = f (R_s/R_0)) for H_2. A set of points are extracted using the WebPlotDigitizer [12] to get a mathematical model that matches the data (Fig.3).

The data obtained by graphic its applied in Excel (Fig.4) to have the sensor eqation like the formula below:

$$\text{MQ2 H}_2\ \text{ppm} = 966.21\left(\frac{\text{R}_\text{s}}{\text{R}_0}\right)^{-2.108} \qquad (6)$$

$$MQ2\ H_2\ \ log\ ppm = \ -2.1075\ log\left(\frac{R_s}{R_0}\right) + 2.9851 \qquad (7)$$

Therefore, the formula of MQ2 sensor for H2 is:

$$MQ2\ H_2\ ppm = \ 10^{-2.1075\, log\left(\frac{R_s}{R_0}\right) + 2.9851} \qquad (8)$$

The MQ series has several models, and different features and different preheating times. Some of these are heated for more than 12 hours until readings become stable.

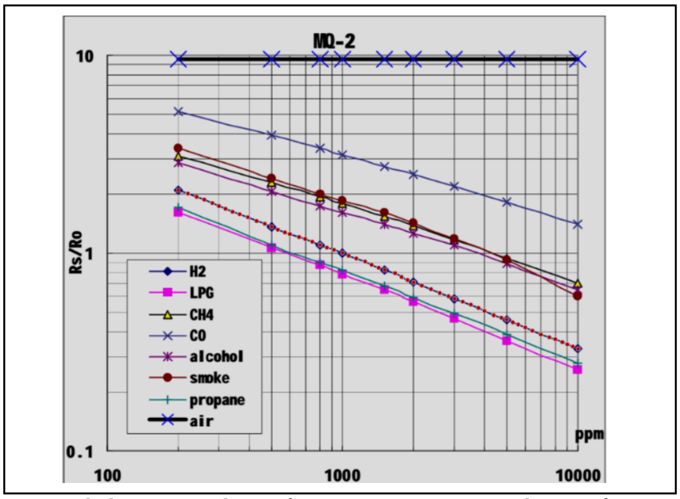

Fig.3. WebPlotDigitizer plotting for MQ2 sensor to exctract the point for H2

In the same way we find the formula for sensor calibration at the beginning (CA-the clean air):

$$\frac{R_{sCA}}{R_0} = f(ppm_{CA}) \qquad (9)$$

$$\frac{R_{sCA}}{R_0} = 9.56 \qquad (10)$$

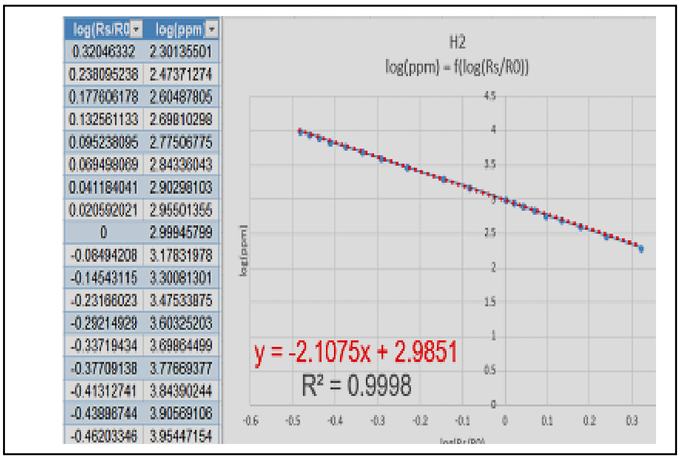

Fig.4. The results obtain after logathim applied to the eqation H_2ppm=f(R_S/R_0)

Similarly, there were the operating equations of all MQ2 sensor gases, as well as the MQ 2-9 and MQ135 series sensors.

Table 1. The equation identified with the methods described above for differents types of gases for MQ2 sensor

MQ 2	$\log \text{ppm} = \log(\frac{\text{R}_\text{s}}{\text{R}_0})$	R^2
LPG	$\text{LPG} \log \text{ppm} = \ -2.1116 \log\left(\frac{\text{R}_\text{s}}{\text{R}_0}\right) + 2.7624$	0.9994
PROPANE	$\text{PROPANE}\ \log \text{ppm} = \ -2.1728 \log\left(\frac{\text{R}_\text{s}}{\text{R}_0}\right) + 2.7997$	0.9994
H_2	$\text{H}_2\ \log \text{ppm} = \ -2.1075 \log\left(\frac{\text{R}_\text{s}}{\text{R}_0}\right) + 2.9851$	0.9996

ALCHOOL	$\text{ALCHOOL} \ \log \text{ppm} = -2.666 \log\left(\frac{R_s}{R_0}\right) + 3.3375$	0.9998
CH_4	$CH_4 \ \log \text{ppm} = -2.606 \log\left(\frac{R_s}{R_0}\right) + 3.6301$	0.9984
SMOKE	$\text{SMOKE} \ \log \text{ppm} = -2.2842 \log\left(\frac{R_s}{R_0}\right) + 3.5803$	0.9982
CO	$\text{CO} \ \log \text{ppm} = -2.9368 \log\left(\frac{R_s}{R_0}\right) + 4.4477$	0.9929

As presented above, the manufacturer provides a general graph to obtain the concentration.
In our sensors, Rs refers to sensor resistance in the presence of certain gases. R_0 is a constant of each sensor and it is computed in the following paragraph. The MQ gas sensor is a resistive sensor and the data acquisition circuit is very simple. A computing algorithm for a voltage divider it is used:

$$R_s = R_L \ (V_c - V_{out})/V_{out} \qquad (11)$$

where,
Rs = sensor resistance (ohm);
Vc = input voltage (volt);
Vout = output voltage (volt);
R_L = load resistance, manufacturer's calibration (ohm)

Calibration is a process to obtain the most accurate sensor data. One of the problems is that each of these sensors is produced to measure different types of gas at the same time. If a sample emitted two or more of the gases the sensor can measure, the results will be inconclusive. To solve this problem is know the measured substance.
The charts provided by the manufacturer are made with a resistive value R_L (charge resistance). It is known V_C, R_L și V_{out} and it is computed R_{sCA} for each sensor using formula (12):

$$R_{sCA} = R_L \ (V_c - V_{out})/V_{out} \qquad (12)$$

After that $R_0$is computed with formula (13):

$$R_0 = R_{sCA}/RatioAir \qquad (13)$$

where $(RatioAir)$ is a constant deducted of the datasheet (14):

$$R_{sCA}/R_0 = f(\text{〖}ppm\text{〗}\_CA) = RatioAir \qquad (14)$$

After R_0 computing, the calibration process is finished.

IV. Arduino / LabView – the calibration circuit for MQ sensors

To find the voltage V_{out} for resistances R_{sCA} and R_0 we build the circuit with Arduino Mega 2560, a voltage sensor and a gas sensor. The circuit is controlled with LabView interface. That, we can monitor the output voltage, compute the sensor resistance R_{sCA} knowing the constant R_0 and saving the data in Excel.

The Arduino board is connected using Arduino Toolkit (LabView) (Fig.5). In Formula Node of LabView is written the gas and voltage sensors equation like formula (12) (13).

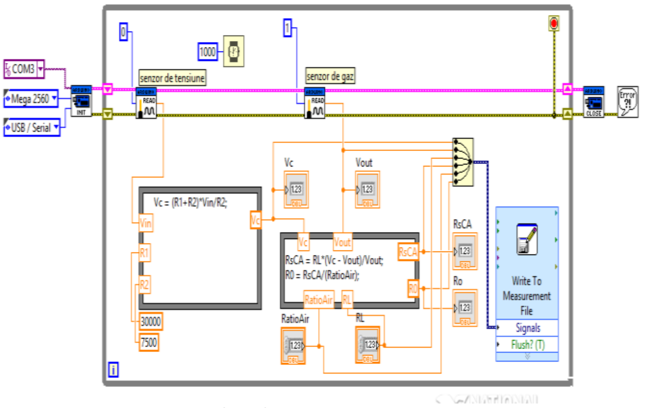

Fig.5. The LabView interface for output voltage computing

All the parameter of the acquisition system are dispayed on the LabView interface (Fig.6). The sensor type can be chosed and the equation results are dispalyed in differents modes, like graphs or tanks.

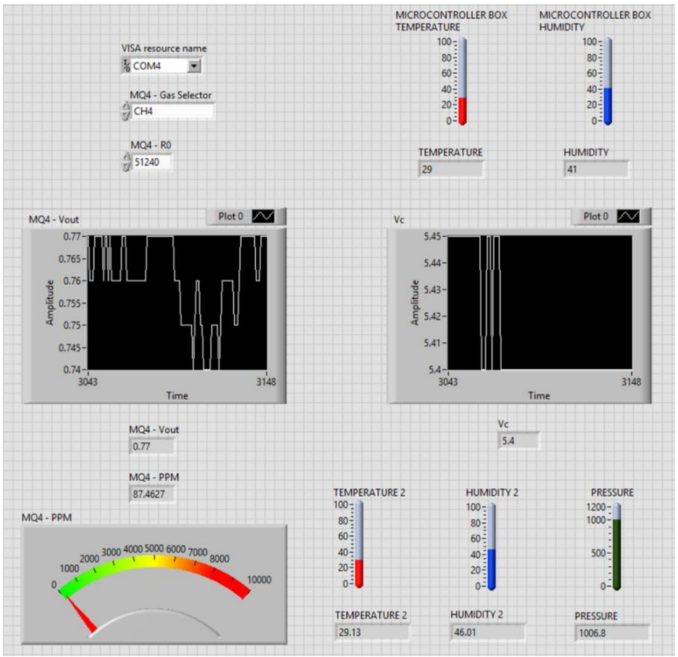

Fig.6. That LabView Front Page interface for gas data acquisition

The constants R_L and $RatioAir$ are initialized with the known datasheet values. The plot results in case of MQ2 sensor for "clean air" Vout and R0 is presented in Fig. 7.

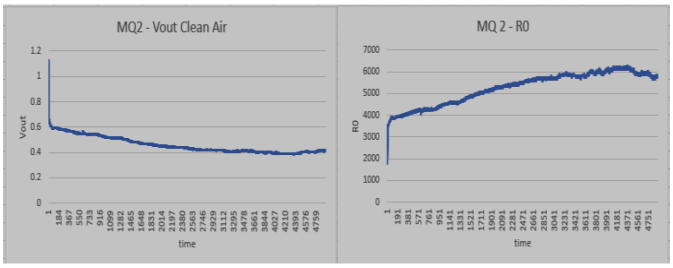

Fig. 7. Output voltage Vout / constant R0 during calibration period in "clean air"

In the same way are plotted the graph for the 2-9 MQ, MQ 135 sensors. In the next table (TABLE II) is presented the R_0 results for 2-9MQ, MQ135 sensors.

TABLE II. THE R_0 COMPUTING FUNCTION OF R_{sCA}

Sensor	$\mathbf{V_c}$	$\mathbf{V_{out}}$	$\mathbf{R_L}$	$\mathbf{R_{sCA}}$	**RatioAir**	$\mathbf{R_0}$
MQ 2	5.02	0.4165	5000	55294.11	9.65	5728.77
MQ 3	5.02	0.5978	200000	1480327.86	59.95	24692.70
MQ 4	5.02	0.4067	20000	226987.95	4.43	51238.81
MQ 5	5.02	0.7644	20000	111410.25	6.48	17192.94
MQ 6	5.02	1.0633	20000	74470.04	9.9	7522.22
MQ 7	5.02	0.5789	10000	76716.18	26.06	6943.82
MQ8	5.02	0.9212	10000	44521.27	69.48	1708.41
MQ 9	5.02	0.5684	10000	78362.06	9.72	8061.94
MQ 135	5.02	0.9653	20000	84060.91	3.6	23350.25

V. THE DATA AQUISITION IN VACUUM

The sensors calibration helps to measurement of different gas concentrations. Using the circuit presented in the second section, we test the sensors behavior in normal air and vacuum (Fig.8-10).

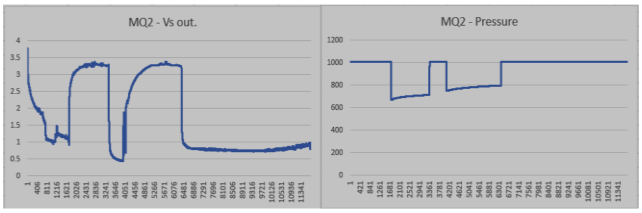

Fig. 8. MQ2 – Vs out versus Vacuum pressure

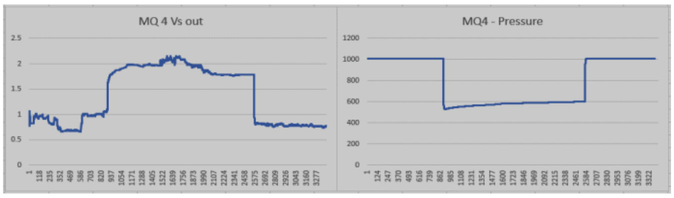

Fig. 9. MQ4 – Vs out versus Vacuum pressure

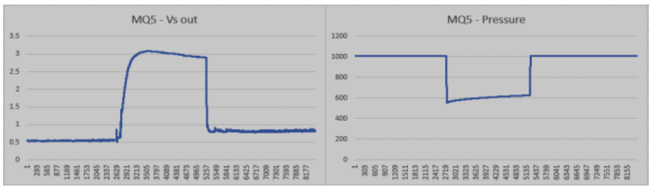

Fig. 10. MQ5 – Vs out versus Vacuum pressure

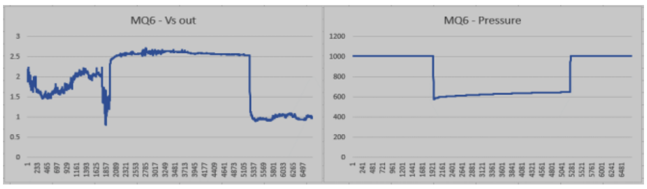

Fig. 11. MQ6 – Vs out versus Vacuum pressure

As can be seen from the high graphs based on the collected data, the gas sensor changes its output voltage due to the lack of O2 in the measurement enclosure. It can be said that in this case the gas sensor behaves like a pressure sensor. The output voltage has the same values for all the gases sensors.

CONCLUSION

This paper describes the calibration methods for MQ family of gas sensors. The formula for sensor calibration for this type of sensors is not completed, so using the data representation we extracted them. We have used the same methods to find the calibration formula for MQ sensor. We test them using LabView interface. All the formula are written in Formula Node virtual instrument and all the software is realized for the sensors network. In final paper, it's presented the sensors behavior in vacuum. This help to the food industry to identify the expired food using cheap system.

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