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High Performance CO_2 Measurement Based on Pressure Modulation

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Abstract

Herein pressure modulation is proposed as a method to increase the resolution as well as to eliminate long term drift of NDIR gas sensors. Measurements are presented that verifies the theoretical predictions of possibility to drift compensation and resolution improvement. The resolution is increased 8.6 times when the pressure is changed from atmospheric to 900 kPa. The method can be applied to existing sensors for both resolution improvement and drift compensation.

Keywords: Carbon Dioxide; Gas Sensor; Pressure Modulation; NDIR

1. Introduction

CO_2 sensors using NDIR (Non Dispersive Infra Red) technique are mature and well known for their high selectivity and good reliability [1]. The principle using IR (Infra Red) absorption is also known for long term stability even in high volume production [2]. However, in order to detect CO_2 or other gases with low concentrations more accurately, resolution must be improved as well as the zero-point stability. Zero-point drift origins from for instance lamp ageing and contamination of the reflective optics. Several methods such as ABC (Automatic Baseline Correction) [3] and dual wavelengths or dual beams [4] have been used to minimize error caused by zero-point drift, but all with different practical drawbacks such as constraints on the surrounding environment or sensitivity to mechanical stress in the optics.

Pressure modulation [5] has been suggested to overcome both the problems with zero-point drift and resolution. The increase in resolution with higher pressure is well known and easily understood by the fact that the partial pressure increases, and it is the partial pressure that is sensed using the NDIR principle.

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1.1. Zero point drift compensation

Beer-Lambert law including the pressure can be written as:

$$T(P,C) = A(t)\cdot e^{-\sigma \cdot l \cdot (\frac{P}{P_0})^{\alpha} \cdot C} \qquad (1)$$

Here *T(P,C)* is the transmitted fraction of IR signal for the gas of concentration *C* at pressure *P*, σ is the absorption coefficient, *l* is the optical path length, and α is a model constant. The pressure model includes both the effect of increased number of molecules as that of pressure broadening of the spectral lines. An un-known time dependent function *A(t)* models the zero-point drift. Since drift is slow, *A(t)* can be considered constant during each pressure modulation.

The zero-point drift can be eliminated from data acquired at two different pressures as:

$$\frac{T(P_1,C)}{T(P_2,C)} = \frac{A(t)\cdot e^{-\sigma \cdot l \cdot (\frac{P_1}{P_0})^{\alpha} \cdot C}}{A(t)\cdot e^{-\sigma \cdot l \cdot (\frac{P_2}{P_0})^{\alpha} \cdot C}} \Rightarrow C = \frac{1}{\sigma \cdot l} \cdot \frac{1}{(\frac{P_2}{P_0})^{\alpha} - (\frac{P_1}{P_0})^{\alpha}} \cdot \ln \frac{T(P_1,C)}{T(P_2,C)} \qquad (2)$$

2. Prototype Implementation

The structure of prototype based on pressure modulation realized here is shown in figure 1(a),

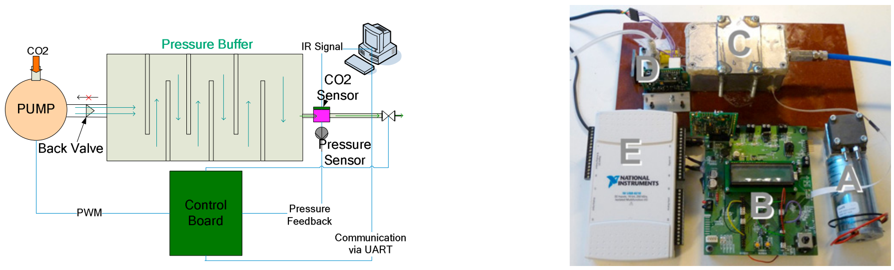

Fig.1. (a) Structure of the whole setup; (b) Hardware of the setup

The setup consists of three parts: pressure modulation, IR signal measurement and the signal analyzer. The first part mainly consists of high pressure pump, pressure buffer, valve, pressure sensor and control electronics; The IR signal measurement is performed by a modified commercial CO_2 sensor K30 from SenseAir with a customized measurement chamber; finally, a PC running LabView performs the signal analysis. Modbus interface is used for communication with the CO_2-sensor, and a NI (National Instruments) DAQ (Data Acquisition) cares for the analogue measurements and control signals.

2.1. Hardware setup

The hardware is shown in figure 1 (b). The pump (A) is customized to be able to generate pressure higher than 900 kPa; the control board (B) generates PWM (Pulse-Width Modulation) signal for pump control, reads the pressure sensor and controls the valves; the pressure buffer (C) makes the pressure control easier due to its gas-volume. It also contains a wall system that suppresses the pulsation of the gas flow, and valves for pressure and flow control. The gas sensor (D) detects carbon dioxide at 4.26 µm wavelength. It is equipped with customized optics that can withstand high pressure. A differential pressure sensor MPX5999D from Freescale with 1000 kPa range is connected to the measurement chamber. The data acquisition unit (E) with 16-bit A/D-converters runs at 250 kHz for acquisition of temperature and pressure signals.

2.2. Software implementation

The microcontroller of the control board (B) in figure 1 (b) runs an independent program for continuous control of the pressure inside the measuring chamber. A PC with a LabView program is used to synchronously collect, treat and store data from the gas, pressure and temperature sensors.

3. Results

For all measurements different mixtures of CO_2 and nitrogen has been used. The relative accuracy of the CO2 content is guaranteed by the supplier to be within ±2% of the nominal value. During the measurements the temperature was within 24±1°C.

Figure 2 shows the measured IR transmission as a function of pressure, and with different CO_2 concentrations. The dots show the measured data, and the lines show a Beer-Lambert function fitted to the data.

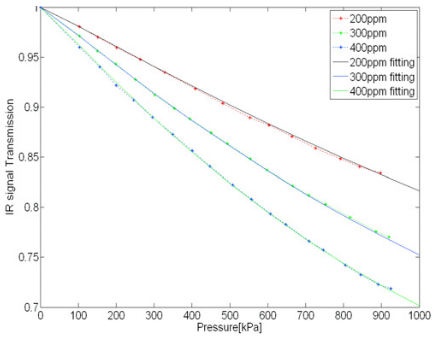

Fig.2. IR-transmission data and fitted Beer Lambert curves for CO2 concentrations of 200ppm, 300ppm and 400ppm

From the graph above one can find that the zero-constant can be obtained by extrapolation of the Beer-Lambert curves to zero pressure.

Figure 3 (a) presents the measured noise of nitrogen at different pressures, and (b) shows the measured sensitivity and resolution at different pressures. At atmospheric pressure the resolution is 43 ppm and at 900 kPa it is 5 ppm. Hence, the increased sensitivity causes 8.6 times increase in resolution.

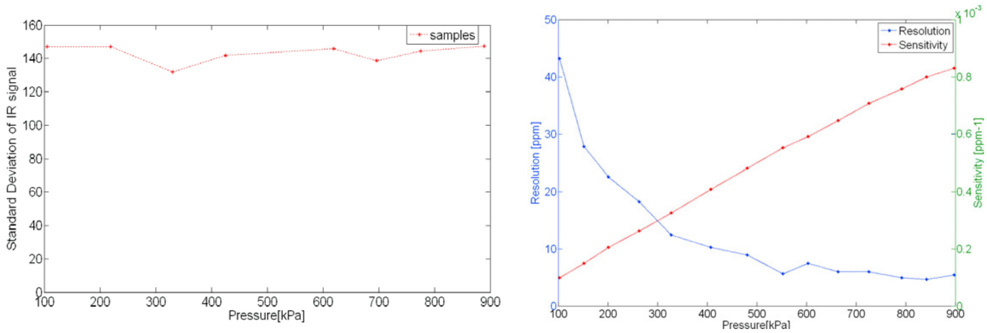

Fig.3. (a) Noise of IR signal at different pressures; (b) Measured sensitivity and resolution as functions of pressure

Figure 4 illustrates the resolution improvement due to increased pressure in practice. Until t_1 pure nitrogen is flushed through the setup at normal pressure, at t_1, 40 ppm CO2 is introduced resulting in signal absorption lower than the detection limit, at t_2 the pressure is increased resulting in a signal that is easily detected due to the improved resolution, at t_3 the over pressure is released and the IR signal goes back to its original level.

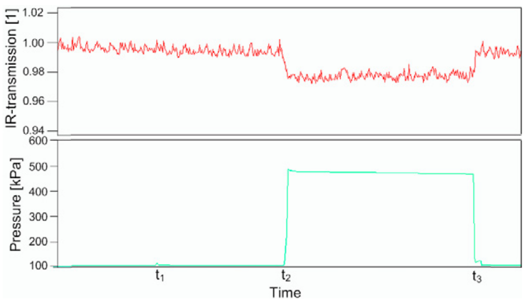

Fig.4. Illustration of the resolution improvement in IR transmission from pressure increase

4. Conclusions

The presented results above show that pressure modulation can solve the problem of zero-point IR signal drift as well as improve the resolution. Conclusions are summarized as follows:

- Pressure modulation does not introduce new noise to the measuring system.
- Sensitivity increases with pressure increment, and here the resolution is increased 8.6 times when the pressure is changed from atmospheric to 900 kPa.
- Pressure modulation at two pressure level can eliminate zero-point drift.
- The modified Beer-Lambert can present the relationship between IR signal and pressure quite well especially in lower concentration.

References

[1] D. Dong et al. Environmental Gas Sensors, IRRR Sensors Journal, vol.1, No.3, (2001) p.214-224.

[2] Web page available at: www.senseair.com.

[3] US pat. No. 11/349,454.

[4] R. Frodl, T. Tille, High Accuracy Spectroscopic Carbon Dioxide Sensor in Bi-source Design with Pressure Compensation. Proc. Of Eurosensors XX, Göteborg, Sweden, September 2006.

[5] Martin, Hans Göran Evald. Arrangement adapted for spectral analysis of small concentrations of gas. International patent publ. no. WO 2010/024 756 A1, 04-03-2010.