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Development of NDIR CO_2 Gas Sensing System Based on U-Shaped Optical Cavity

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ABSTRACT

In this paper, a proposed carbon dioxide Gas Sensing System of high precision, rapid reaction, compact size and low power consumption rate is presented based on the non-dispersive infrared (NDIR) measurement. This system used to determine CO_2 gas concentration in air; it consists of the single broadband light source, U-shape tube optical path cavity as gas cell, thermopile detector, and microcontroller circuit. This study investigates the efficiency of the U-tube optical path cavity at CO_2 gas concentrations ranging from (0-5000) ppm. The obtained results show that it has the better thermal response compare to the linear tube and exhibits high sensitivity by change the transmitted light intensity into analog voltage. The proposed system design can be used as an environmental monitoring sensor.

KEYWORDS: Non-dispersive infrared sensing; CO_2 gas; U-tube optical path cavity.

الخلاصة

في هذا البحث، تم اقتراح نظام استشعار غاز ثاني أوكسيد الكربون عالي الدقة، سريع التفاعل، صغير الحجم وذو معدل استهلاك منخفض للطاقة مستند على مقياس الأشعة تحت الحمراء غير المشتتة (NDIR). يستخدم هذا النظام لتحديد تراكيز غاز ثاني أوكسيد الكربون في الهواء: وهو يتألف من مصدر ضوء عريض النطاق واحد، تجويف مسار بصري على شكل حرف U كخلية غاز، كاشف حراري، ودائرة متحكم الكتروني دقيق. تبحث هذه الدراسة في كفاءة تجويف المسار البصري للأنبوب على شكل U في تركيزات غاز ثاني أوكسيد الكربون التي تتراوح من (**0-5000**) جزء في المليون. أظهرت النتائج المتحصل عليها أن لديها استجابة حرارية أفضل مقارنة بالأنبوب الخطي وتظهر حساسية عالية من خلال تغيير شدة الضوء المرسل إلى جهد تناظري. يمكن استخدام تصميم النظام المقترح كمستشعر مراقبة بيئي.

INTRODUCTION

Carbon dioxide (CO_2) measurement has recently been a hot topic in the harsh environment due to CO_2's impact on air quality [1], global warming [2] and respiratory diseases [3]. Non-dispersive infrared gas sensors (NDIR) and contact type gas sensors such as Semiconductor Metal Oxide and Electrochemical have been employed in CO_2 monitoring. The NDIR gas sensors are suitable for real-time or long-term operation because of their low power consumption, small size, good gas selectivity, and extended lifetime [4-6]. As a result, NDIR CO_2 gas sensors are the best and most straightforward technique to ensure consistent CO_2 monitoring output. The optical gas detection sensors (NDIR) are based on the absorption spectrum method of physical sensing. Several studies tried to improve the measurement capability. A closed-loop feedback system modeled to measure gas concentration the duty of heating. The obtained results illustrate a good behavior of signal and it proves to be a practical for all the NDIR measuring techniques [7]. Other study used an Optical sensor exploiting the mid-infrared light absorption of CO_2. In particular, by increasing carrier-heating time, the carrier Temperature is increased [8]. This method provides high selectivity, but their large size and high cost limit their use [9]. In the current study, CO_2 gas is monitoring based on the NDIR approach indoor and outdoor. The gas is illuminated by light with a wavelength of 4.26 µm, thus the CO_2 molecules absorb the light in the chamber and reducing its intensity. Then, by measuring the light absorption, the gas concentration will be measured.

CO_2 Non-dispersive infrared gas detection

At a wavelength of 4.26 m, the CO_2 molecules absorb the infrared spectrum. When infrared light strikes CO_2 molecules, the gas absorbs the energy of the beam depending on the amount of the CO_2concentration. The Lambert-Beer law applies to CO_2 absorption. The Lambert law states that the transmitted light intensity is as follows [10]:

$$I = I_o exp^{-KCL} \quad (1)$$

where, I_o is the intensity of light incident on the sa mple (gas), where I is the measured intensity of light transmitted from the sample (gas), and K represents the gas absorption coefficient, which is dependent on the gas sample type, spectral wavelength, pressure, temperature, and other factors (cm^2). C stands for sample gas concentration ($1/cm^3$), and L is for cell chamber length (cm) [4, 11].

MATERIALS AND METHODS

Figure 1 shows the proposed experimental setup for the NDIR gas sensing system as assembled in the laboratory. It consists of a modulated IR source, an optical cavity U-shape tube (optical path), dual channel thermopile detector and an amplifier circuit with micro-control, and other components. The CO_2 content is determined by its absorption of a certain wavelength in the infrared area after the gas is diffused into the sample gas chamber. The gas cell directs the IR light source towards the thermopile. The thermal background signals are offset from the intended signal by modulating the signal light from the source light bulb. The sensitive wavelength of CO_2 gas and the light intensity of the reference wavelength are measured using a dual channel thermopile detector. The thermopile detector's output voltage signals are relatively feeble. Filtering weak signals to remove noise and amplify signals is required. The light intensity is not modified for another reference light since the light is not absorbed by the CO_2 molecules. y measuring the absorption of light, the concentration of the measured gas will be computed. The detector measures the maximum light intensity when the CO_2 gas concentration in the chamber is zero.

The amount of light on the thermopile detector decreases as CO_2 concentration increases [6]. The infrared source lamp can emit a wavelength of (VIS –IR) range (from 0.3 to 5 µm). This range based on the data sheet shown in Figure 2, which meets the experiment requirements that switched at a low frequency. IR source is electrical modulated frequency with frequency changes in a range from (0.5 to 3 Hz) [2].

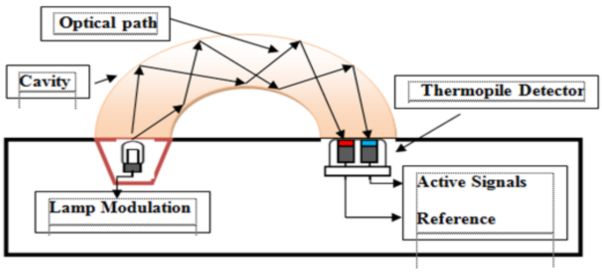

Figure 1. Prototype of the proposed experimental setup of NDIR gas sensing system.

Moreover, the IR thermopile detector has two channels with a center wavelength and half power bandwidth (4.26 µm) for CO_2 channel and (3.95 µm) for the reference channel respectively.

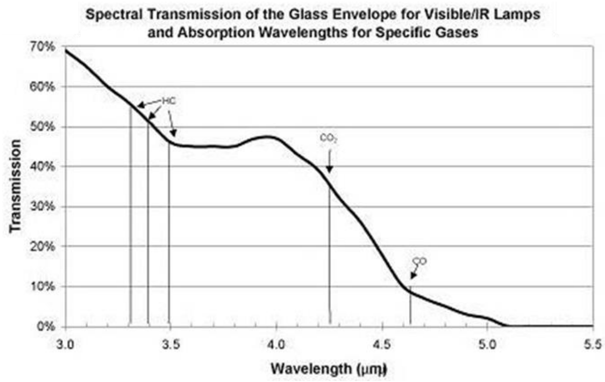

Figure 2. The curve indicates the lamp's transmittance at wavelength [2].

RESULTS AND DISCUSSION

The experimental results of the proposed NDIR CO_2 sensor are presented in this section based on the calibration methods in indoor utilizing pure nitrogen gas (0 ppm CO_2). in order to duplicate the conditions under which the sensor was originally calibrated at the factory. Nitrogen calibration is also required if CO_2 levels between 0-400 ppm will be measured.

Automatic background calibration means to calibrate with characteristics that the outdoor concentration of CO_2 is about 400 ppm normally. When the levels of CO_2 molecules in the chamber are zero, the thermopile detector reads the full intensity of the light. As the CO_2 molecules concentration increases, the light intensity at the thermopile detector is reduced. In addition, by using an account formula for CO2 concentration (C_{ppm}) between (0ppm-5000ppm) that gets by Analog output voltage (V_{out}), as follow [12]:

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$$C_{ppm} = (V_{out} - 0.4) \times (5000/2 - 0.4) \quad (2)$$

In this case, the V_{out} is between (0.4V and 2V) for an output range between (0ppm and 5000ppm). Moreover, Figure 3 a, b, c, d, e and f illustrate the experimental measured absorbance of the analog output signal versus CO_2 concentrations. Figure 3a represents amplitude pulse value of (V=1.3 V) at concentration value (C_{ppm}=2812 ppm), Figure 3b represents amplitude pulse value of (V=1.4 V) at concentration value (C_{ppm} = 3125 ppm), Figure 3c represents amplitude pulse value of (V = 1.5 V) at concentration value (C_{ppm}=3437 ppm), Figure 3d represents amplitude pulse value of (V=1.6 V) at concentration value (C_{ppm} = 3750 ppm), Figure 3e represents amplitude pulse value of (V=1.7 V) at concentration value (C_{ppm}=4062 ppm) and Figure 3f represents amplitude pulse value of (V=1.9 V) at concentration value (C_{ppm}=4680 ppm). Thus, the new sensor, which has the better thermal response compare to the linear tube [13, 14]. Also, it exhibits high sensitivity by change the transmitted light intensity into analog voltage [15]. Therefore, it can be utilized as an environmental monitoring sensor [16].

Also, Figure 4 shows the linear relation of the experimental results as a function of gas CO_2 concentration at room temperature (T= 27 °C).

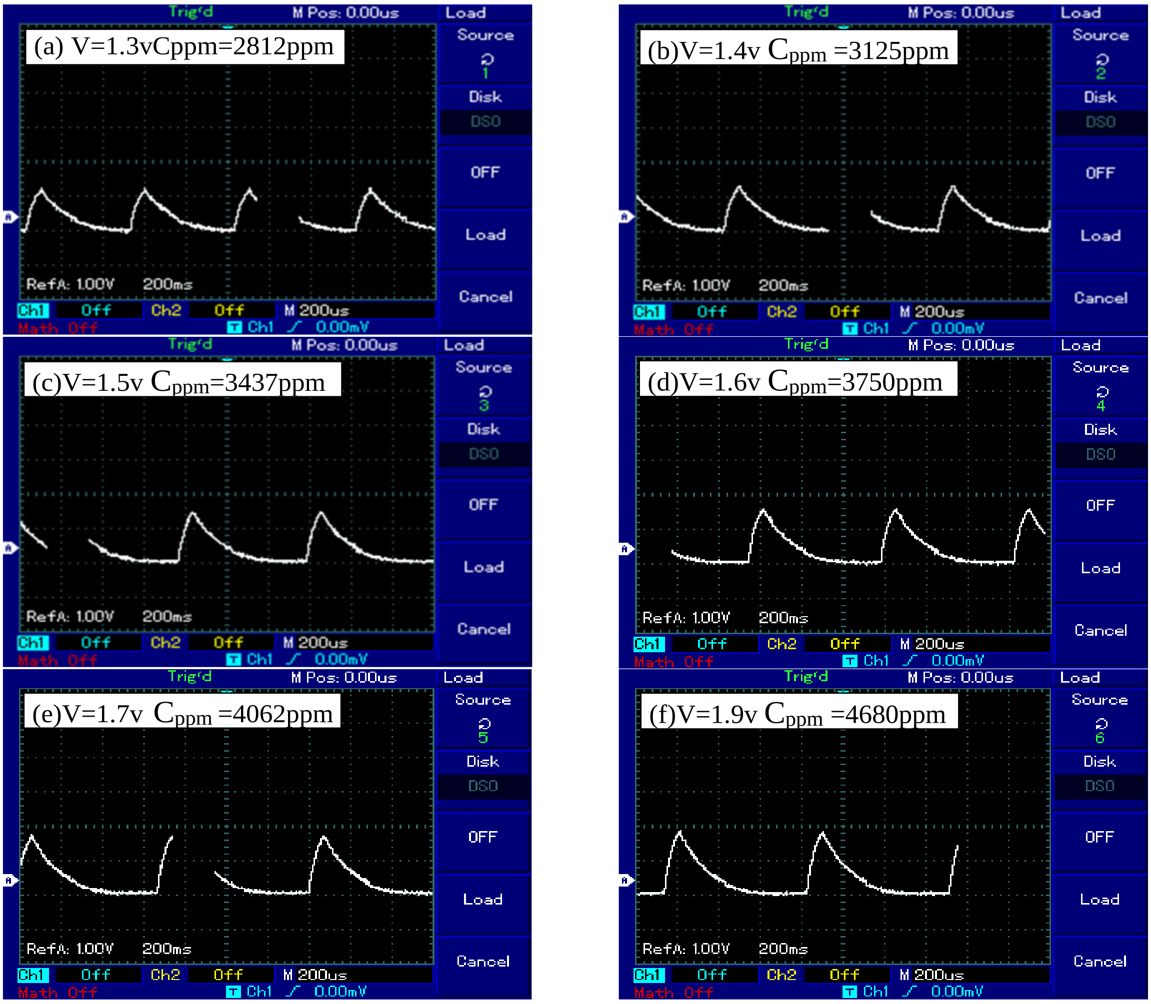

Figure 3. a), b), c), d), e) and f) Represent the output Analog voltages (signals) for six cases at different gas concentrations.

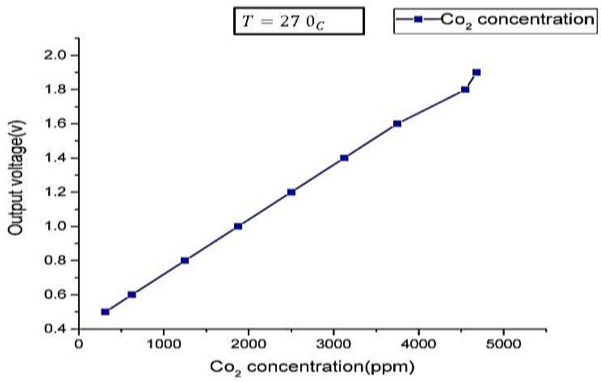

Figure 4. Shows the experimental results as a function of gas CO_2 concentration at T= 27C°

CONCLUSIONS

In this research, a developed air quality monitoring system based on principle of NDIR is proposed and implemented. This system used to determine CO2 gas concentration in air through change the transmitted light intensity into analog voltage. The built-in U-shape tube optical path cavity as gas cell with thermopile detector, increase the sensitivity of NDIR sensor at CO2 gas concentrations ranging from (0-5000 ppm). The obtained results show that it has the better thermal response compare to the linear tube and exhibits high sensitivity by change the transmitted light intensity into analog voltage. The proposed system design can be used as an environmental monitoring sensor.

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Disclosure and conflict of interest: The authors declare that they have no conflicts of interest.

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