

A Hybrid Gas Sensor based on Infrared Absorption for Indoor Air Quality Monitoring

Marianah Masrie, Ramli Adnan and Anuar Ahmad

Abstract— A hybrid gas sensor based on infrared absorption has been developed for indoor air quality monitoring. The sensor is used to measure the concentration of carbon dioxide (CO₂) and carbon monoxide (CO) to 1 part per million (ppm) level in indoor environment. Photoresistor PbSe was used as a sensor in order to measure two gases at the spectrum absorption band of 4.3 μm and 4.6 μm due to CO₂ and CO molecules in the air respectively. The infrared lights are emitted by two light emitting diodes (LEDs). These light sources are much smaller, high speed, with low power consumption and does not need optical filters. The design of the prototype sensor system and results are presented in this work.

Index Terms—Gas sensor, infrared absorption, IAQ, LED, photodetector.

I. INTRODUCTION

Indoor air is the air that we breathe in indoor environment such as at homes, offices, hospitals, etc. Based on a study, people spend most 90% of their time indoors where they are exposed to far greater air pollution risks than at the outdoors [1]. The importance of indoor air quality (IAQ) in Malaysia is recognized by the Department of occupational safety and health (DOSH), who released a revised set of a Code of practice on Indoor Air Quality in July 2005, through the Ministry of Human Resources Malaysia [2]. In recent years, there has been an increasing interest in developing IAQ monitoring system for detecting and measuring indoor air pollutants based on infrared absorption in mid infrared region. However, most of the developed system can only measure one type of gas concentration [3, 4]. The previous developed systems employed thermal source as an infrared emitter [5-7] and there are disadvantages of using this type of source [8, 9]. It also employed detector which need an optical filters in order to achieve selective detection of the target gases [6, 10]. This

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system utilizes mid infrared LED which provides light source emitted at 4.3 μm and 4.6 μm due to CO₂ and CO molecules in the air. This light source is much smaller, high speed, with low power consumption and does not need optical filters [11]. A photoresistor is used to measure CO₂ and CO, while a photodiode is used to provide a reference measurement. Apart from that, the system can measure relative humidity and temperature.

II. SYSTEM ARCHITECTURE

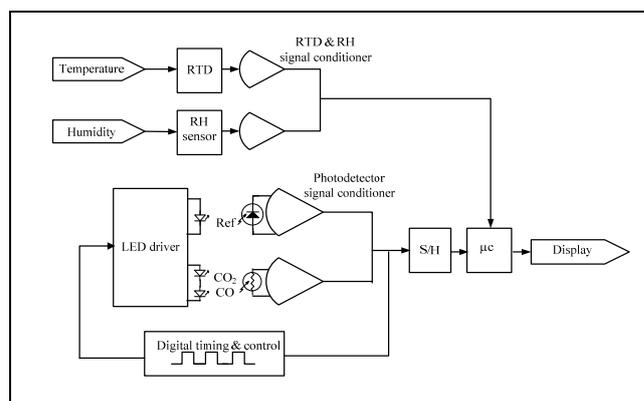


Fig. 1. Overview of hardware development and software integration

Fig. 1 shows the overview of hardware development and software integration of hybrid gas sensor system for indoor air quality. It consists of mid infrared LEDs as infrared light source which was driven by LED driver. The digital timing and control circuit generates three quasi continuous wave signals (quasi-CW) in three sequences to control the LED driver. It also generates three wave signals in quarter phase of the signals driven the LEDs to be fed to the sample and hold circuitry. The light signals emitted from the LEDs with modulation frequency of 1 kHz are travelled along in a chamber in which the infrared light interacts with gas molecules; CO₂ and CO in the air. The infrared lights absorbed by the gas molecules are detected by two photodetectors. The signals are conditioned before being fed to the sample and hold. Apart from that, a humidity sensor

(RH) with integrated precision resistance temperature detector (RTD) is also included for humidity and temperature measurement in the system. PIC16F877A is used as a microcontroller for the data acquisition and provides liquid crystal display (LCD) control functions to operate the display.

A. Infrared Light Emitter

The LED driver circuit of Fig. 1 employed three mid-infrared LEDs: LED 38 (LED reference); LED 43 (CO₂) and LED 46 (CO) as the light sources. Table I shows the gas molecules spectrum absorption band in mid infrared region and the respective LEDs.

TABLE I
GAS MOLECULES AND ITS EQUIVALENT SPECTRUM ABSORPTION WAVELENGTH

Gas molecules	Spectrum absorption (nm)	LED	MIR LED wavelength (nm)
CO	4600	LED 4.6	4600
CO ₂	4230	LED 4.3	4300

The LED driver was designed to operate the LEDs with 150 mA DC current. The 150 mA DC current was obtained using LM358 op-amp 2N2222A bipolar junction transistor (BJT) with the quasi-CW from the digital timing and control as the input voltage. The modulation frequency of 1 kHz was chosen and therefore, LED 43 and 46 were pulsed ON for 250 μ s at duty cycle 25 % while LED 38 for 125 μ s at duty cycle 12.5%. The LEDs were pulsed OFF for 125 μ s at duty cycle 12.5%.

A. Photodetector Signal Conditioner

The emitted infrared light from the LEDs were detected by two photodetectors: infrared light emitted from LED 38 was detected by photodiode PD 36 with wavelength of 3.6 μ m; while the infrared light from LED 43 and LED 46 were detected by photoresistor PR 43 with peak wavelength of 4.3 μ m. The signal conditioning circuit was designed to convert the detected light from the photodetectors to voltages. This voltage is proportional to the intensity of the received light. The signal conditioning circuit for the photodiode is divided into three stages: pre-amplification; amplification; and zero and span. The photoresistor has two stages: pre-amplification; and zero and span. The pre-amplification for the photodiode is current to voltage converter while for the photoresistor is voltage to voltage converter.

The circuits were also designed to reject noise at the pre-amp stage that associated with op-amps and photodetector itself. The noise that normally interfered with the signals are zero frequency (DC) component due to sources like sunlight, 120 Hz due to ambient light such as incandescent lamp and flicker noise, 1/f. The technique to reject zero frequency components is by measuring the signal of the background level when all LEDs are pulsed OFF. The background signal was subtracted from the measured signal when LED was pulsed ON, therefore, the difference signal value enhanced the spectrum absorption. The 120 Hz ambient light can be removed by employing high-pass filter in the signal conditioner circuit and low-pass filter was used to attenuate any high frequency noise picked up in the amplifier. The flicker noise, 1/f was appeared below frequencies of few Hz in this sensor due to imperfection in manufacturing process of the component. In order to reduce this noise, the sensor was shielded with grounded metal plate. This method prevents the electromagnetic radiation from inducing noise into the internal circuitry. The design of the analog filtering was based on simulation results that were done using MATLAB Simulink. From the simulation, the values of resistors and capacitors of the filters can be selected based on the optimum gain obtained from the simulation results.

B. Software Integration

The microcontroller was operated as it programmed by capturing analog data from signal conditioner, performing analog to digital conversion, data processing and displaying the results through display panel. Two algorithms were designed for the microcontroller in order to acquire the analog data from the gas sensor and relative humidity sensor. Both of the programs consist of main program which has subroutines for each of the analog output of the sensors. The analog outputs are, CO₂, CO, background, reference signals which is captured from photodetector signal conditioner. The other analog outputs are from relative humidity signal conditioner. To enhance the spectrum absorption, the background signal is subtracted from the signals of CO₂, CO and reference. The ratio of the difference between gas and background signals to the difference between reference and background signals provide the full gas concentration which is shown in (1), where Meas is gas measurement for the target gas, ref is reference measurement and Bg is background measurement. The data calculation was done in accordance to this equation. The data conversion to ppm reading was done using data manipulation program by calibrating the sensor against standard instruments.

$$\text{Gas Concentration} = \frac{\text{Meas} - \text{Bg}}{\text{Ref} - \text{Bg}} \quad (1)$$

C. Humidity Sensors

HIH-3602-C sensor from Honeywell has internally two independent circuits to measure humidity and temperature [12]. The humidity sensor has integrated signal conditioning with the output voltage typically spans from 0.8V to 3.9V for the 0% and 100% relative humidity (RH) range at 25°C. However, the signals are conditioned from 0V to 2.5V for PIC input signals requirement. The temperature sensor comprise with 1000 Ω platinum resistor (RTD), and is mounted in a Wheatstone bridge with three 1K resistors. The signal output of the bridge is amplified with gain of 11dB.

III. RESULTS AND DISCUSSION

A. LED Response

The LED reference (LED 38) was designed to have an ON time of 125 μs and OFF time of 875 μs with 12.5% duty cycle. The quasi-CW for the LED reference at channel 1 is 1.083 kHz and duty cycle of 12.41% as shown in Fig. 2. The quasi-CW at channel 1 was divided into half for all LEDs in Off condition to provide background measurement as highlighted in Fig. 2. LED 43 and LED 46 were designed to operate with ON time of 250 μs and OFF time of 750 μs with 25 % duty cycle. As can be observed from Fig. 2 the quasi-CW at 3 and 4 are assigned for, LED 43 and LED 46. The frequency is 1.083 kHz and the duty cycle is 24.97 %.

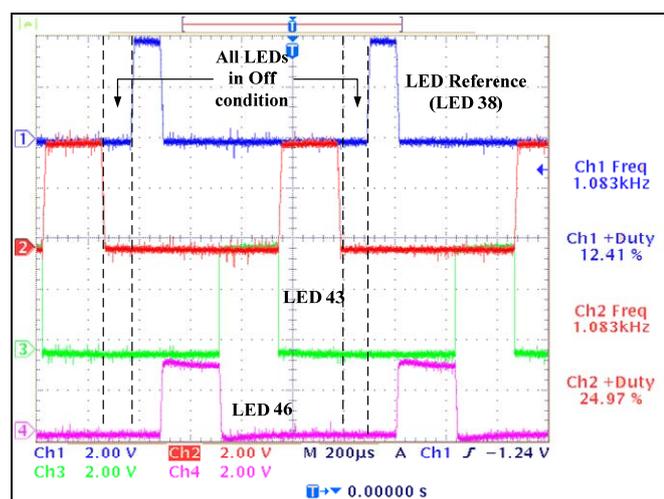
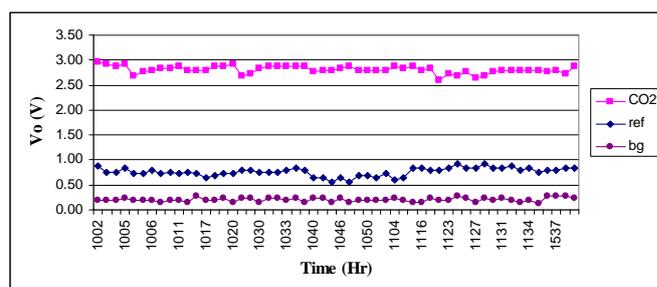


Fig. 2 Frequency and timing diagram

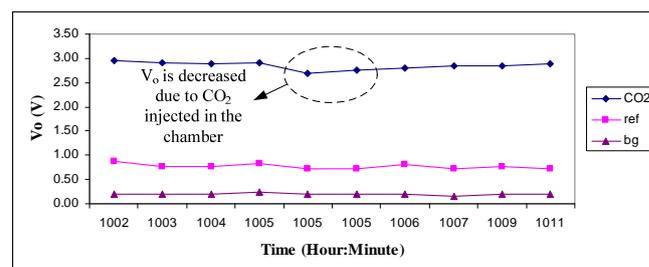
B. Prototype Sensor Response

The performances of the developed system were evaluated using gas chamber with normal ambient air. The sensor was tested using CO₂ Water Plant Disposable Can for CO₂ evaluation and exposing the sensor to cigarette smoke for CO evaluation. In the experiment, the suction fan is used to draw the gas into the chamber and the remaining gas in the chamber is cleared up using exhaust fan.

Fig. 3 shows the experimental results on CO₂ voltage variation from sample and hold. The voltage variation between the ambient air and the presence of CO₂ gas is given in Fig. 3(a). It can be seen that the output voltage is approximately constant until the chamber is filled up with CO₂ gas. Once the gas was trapped in the chamber, the molecules absorbed the respective infrared light based on the spectrum absorption wavelength. Strong evidence of CO₂ concentration exist as the outputs voltage decreased. The voltage received by photoresistor PR 43 is inversely proportional to the gas concentration in the chamber. As the CO₂ concentration increases, the intensity of light reaching the detector decreases due to gas absorption. The voltage reduction can be seen clearly in Fig. 3(b).



(a) Voltage variation between ambient air and CO₂ gas presence

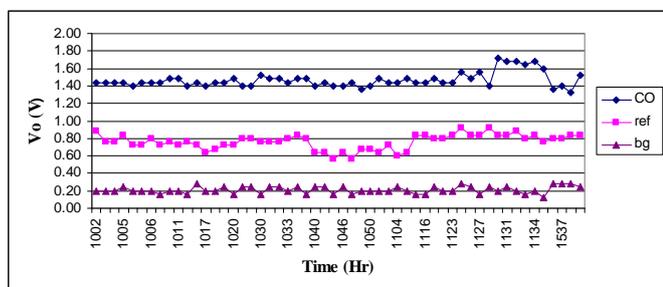


(b) Decreasing voltage due to increasing in CO₂ concentration

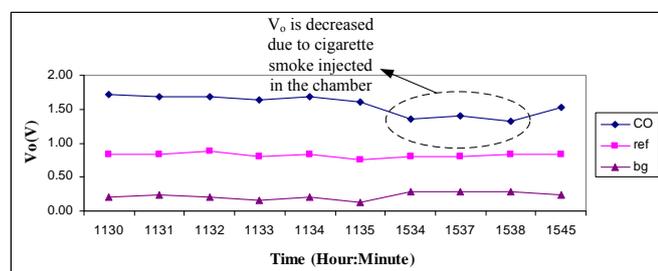
Fig. 3 Experimental results on CO₂ voltage response from sample and hold

Fig. 4 shows the experimental results on CO voltage variation from the sample and hold. The measurements were

done with the chamber exposed to cigarette smoke. The output voltages were decreased with higher concentration of CO which can be seen in Fig. 4(b). This result gives strong evidence for the presence of higher CO concentrations.



(a) Voltage variation between ambient air and CO gas presence



(b) Decreasing voltage due to increasing in CO concentration

Fig. 4 Experimental results on CO voltage response from sample and hold

The reference (Ref) output voltage shown in the given figures remained constant since CO₂, and CO molecules are not absorbing infrared light at these wavelengths.

C. Prototype sensor performance

In order for the prototype sensor system to have correct measurement of the tested gases, calibration was done by comparing the prototype sensor to those commercial standards CO₂ and CO gas detector. The developed software is able to convert the gas concentration ratio that given by (1) to digital values. These values are free from noise since the measurement values had been subtracted from the background value of 200 mV. The calibration was done at ambient air at 23 °C for all type of gas measurements.

Table II and III show the comparative measurements between the prototype sensor and the commercial detectors for CO₂ and CO concentration. The concentration range of CO₂ was approximately from 260 to 275 ppm at 23°C as given in Table II. The maximum accuracy is 0.05 ppm and the minimum accuracy is 0 ppm. For CO measurement, constant values were obtained which measured by the prototype sensor

as the reference sensor measurement values are not constant. The comparative measurements can be seen in Table III. However, these values are in the range of measurement that is made by standard instruments. The maximum and minimum accuracy for CO are 0.71 and 0 ppm.

TABLE II
CO₂ CONCENTRATION

Prototype (ppm)	Reference (ppm)	Accuracy (ppm)
263	250	0.05
263	251	0.05
263	252	0.04
273	261	0.05
273	262	0.04
263	262	0.00
263	263	0.00
263	265	0.01
273	266	0.03
263	267	0.01
273	273	0.00
273	274	0.00

TABLE III
CO CONCENTRATION

Prototype (ppm)	Reference (ppm)	Accuracy (ppm)
0.2	0.2	0.00
0.2	0.7	0.71
0.2	0.2	0.00
0.2	0.7	0.71
0.2	0.2	0.00
0.2	0.2	0.00
0.2	0.2	0.00
0.2	0.2	0.00
0.2	0.2	0.00
0.2	0.2	0.00
0.2	0.2	0.00

IV. CONCLUSION

The hybrid gas sensor system for indoor air quality

measurement based on infrared absorption for measuring CO₂ and CO has developed and tested. The output of the sensor has shown some convincing response to the relative CO₂ and CO concentration. A low-cost microcontroller was employed; it was able to manipulate the gas concentration by converting the signal into a digital display reading. This prototype stage of integrated IAQ measurement system has demonstrated that it can measure the concentration of CO₂ and CO gas with a very high resolution due to the high signal amplification used.

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