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Effect of Temperature, Pressure and Humidity on Carbon Dioxide Concentration—Simulation Study

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Abstract. The growing application of infrared carbon dioxide (CO2) sensor now needs an accurate and precise measurement of human respired CO2 concentrations. CO2 concentration measurement is influenced by a number of environmental parameters. The objective of this study is to perform a simulation study on the list of environmental parameters which have a major influence on the precision and accuracy of the infrared CO2 sensor. Here, we designed a CO2 concentration estimation circuit that comprises temperature, pressure and humidity sensor, Arduino Uno, and liquid crystal display. Besides, a program is written and uploaded to the Arduino board to compute the CO2 concentration. A simple mathematical equation is employed to calculate the instantaneous CO2 concentrations with respective temperature, pressure and relative humidity. We observed a change in CO2 concentration from 31.11% to 30.60% and 21.25% to 26.18% corresponding to changes in temperature from 25oC to 30oC and pressure 21.53kPa to 26.52kPa, respectively while keeping the temperature (250C) and pressure (31.52kPa) constant with respect to each other. In addition, with a change in relative humidity from 28% to 30%, change in CO2 values (6.26% to 9.39%) were observed while temperature kept at 25 0C. Results show that pressure, temperature, and relative humidity have a significant effect on the output of CO2 concentration. Hence, this should not be underestimated while developing a CO2 sensor and barometric pressure, temperature, and relative humidity sensor should be integrated with CO2 sensor for automatic adjustment in CO2 concentration based on the current pressure, temperature and humidity in contrast to manual.

1. Introduction

Accurate and precise measurement of human respired carbon dioxide (CO_2) can reveal significant information about the cardiorespiratory conditions [1-9]. Conventional methods to measure human respired CO_2 are optical based that employs the infrared spectroscopy, fluorescence and gas chromatography [10-18]. The infrared CO_2 sensors seem to be cost-effective and highly sensitive. However, the use of the sensor is limited by environment factors (Temperature, Pressure and Humidity). As, the correction of environmental factors implemented in the firmware while developing the sensor, which can be altered by manufacturer. In the pipeline, real-time CO_2 concentration measurement must take in-situ processing, "in-situ sampling and in-situ monitoring", technology [10], the accuracy of measuring CO_2 concentration influenced by current locations temperature, pressure, and humidity [11]. Hence our interest is to figure out the most influencing environmental parameter that has a significant effect on the CO_2 concentrations.

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1.1 Working principle of infrared carbon dioxide sensor

Infrared CO2 sensor detects each carbon dioxide gas molecule in a specific spectrum as presented in Figure 1. The gas molecule transition to a higher energy level after absorbing the spectral energy at a rate. This reflects attenuation of light after crossing through the gas. The process of the incidence and absorbance of CO2 molecules follows the Beer Lambert's law that can be expressed as a mathematical function as follows:

$$L = L_0 e^{-\beta \mu t} \quad (1)$$

where L, indicates the light intensity strike on the detector (L, W/cm^2), L_0 is known intensity of the empty chamber (L_0, W/cm^2), β is the absorption coefficient (β, cm^2/mol), μ represents the CO_2 concentration (μ, cm^2/mol), and t denotes the absorption path length (t, cm).

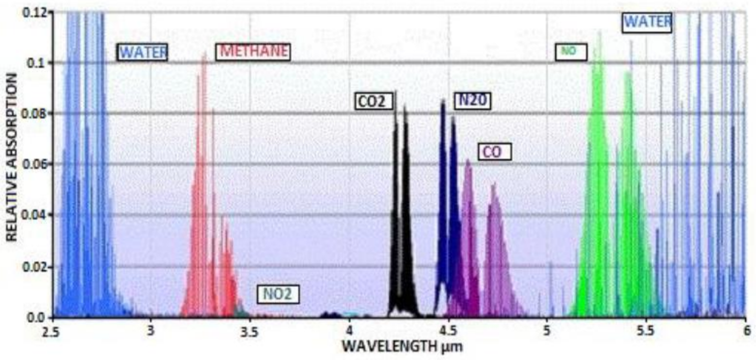

Figure 1. Relevant spectral distribution of the MID-IR light source, the CO2 absorption bands and water vapour [5].

The gas absorption rate of light energy can be written as:

$$P = \ln \frac{L_0}{L} = K_V C t \quad (2)$$

The CO_2 gas concentration can be calculated from the above mathematical function as follows:

$$C = \ln \frac{L_0}{L} \Big/ K_V t = K_V C t \quad (3)$$

The working principle of non-dispersive infrared (NDIR) carbon dioxide detection is detecting the infrared light wave's intensity changes; prior and later light diffuse the specimen gas cell. Through this principle, maximum CO_2 gas concentration can be achieved in a light path. The infrared absorption spectra of CO_2 gas molecule are mainly distributed in 2.01μm and 4.25μm two characteristic regions [12]. The absorption peak intensity differs via three magnitude orders.

Thus, this study aims to design a CO_2 estimation circuit using proteus by employing pressure, temperature and humidity sensor and a simplified mathematical equation. Besides, the mathematical equation is implemented into Arduino IDE to estimate the CO_2 concentration based on the temperature, pressure, and humidity.

2. Methodology

Figure 2 elucidates a hypothesized CO_2 monitoring system based on an automatic compensation for the real CO_2 gas concentration by incorporating temperature, pressure and humidity chip. The CO_2 estimation may possibly employ an infrared light source and detector in integration with temperature, pressure and humidity sensor, Arduino Uno as a microcontroller (AtMega328) and liquid crystal display (LCD). An iteration numerical method may be possibly incorporated with the hypothesized CO_2 sensor in order to compensate the environmental factors for adjusting the CO_2 concentration as presented in Fig. 2. This study presents a simulation study performed for the computation of CO_2 concentration using Proteus by integrating the environmental factor sensors, and Arduino Uno as illustrated in the subsequent sections.

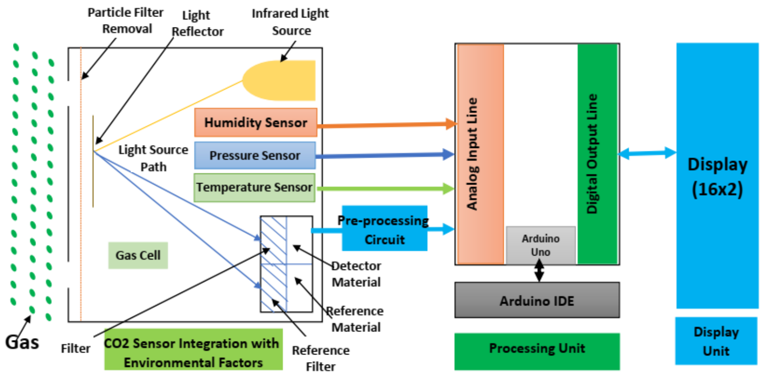

Figure 2. Hypothesized carbon dioxide monitoring system, incorporated environmental sensors.

2.1 Circuit design for CO_2 concentration estimation.

The circuit design for the estimation of CO_2 concentration is presented in Figure 3. The temperature, pressure and humidity sensor were attached to the analogue pin of an Arduino Uno. A program was written into Arduino IDE to compute the CO_2 concentration by modelling the mathematical equation based on temperature, pressure and humidity values. The mathematical equation was employed for the computation of CO_2 concentration is illustrated in the (4) that reflects the relationship among temperature, pressure and CO_2 concentration. The effect of the relative humidity (RH) on the CO_2 concentration is computed by estimating the water vapour pressure based on the RH and saturated vapour pressure (P_s) at the room temperature (25 °C) using (5) and (6).

$$C(T,P) = C\,(25°C, 760mmHg)\ \frac{P}{760}\ \frac{298}{273+T} \tag{4}$$

where C, P, and T are the gas volume concentration in parts per million (PPM), ambient pressure and temperature.

$$P(w) = P_S \times RH \tag{5}$$

where P(w), P_s, and RH reflects the water vapour pressure, saturate pressure, and relative humidity.

$$P_S(t^{o}C) = (0.61078*7.501)e^{\frac{17.2694t}{283.3+t}}\ \text{mmHg} \tag{6}$$

where t and P_s are the actual temperatures and saturated pressure.

Further, the estimated water vapour pressure value was substituted in (4) from (5) to compute the CO_2 concentration with a change in RH.

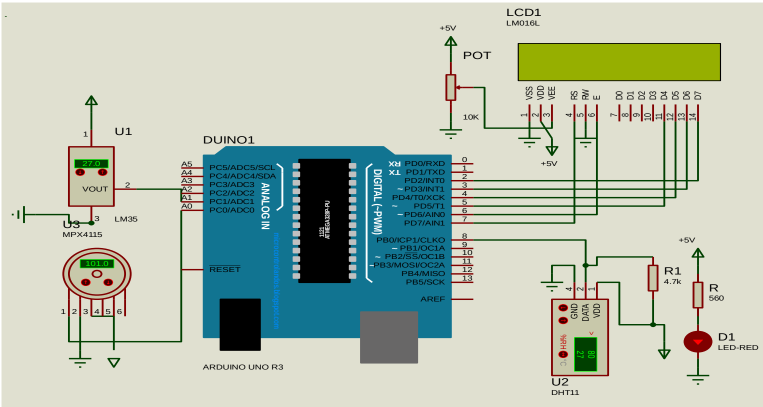

Figure 3. Circuit design for the estimation of CO_2 concentration using temperature, pressure, and humidity sensor.

2.2 Procedure for CO_2 concentration estimation

An algorithm was developed for the computation of CO_2 concentration as presented in Figure 4. The Arduino library was included into Proteus library in order to call the Arduino Uno. Thereafter, open the designed schematic circuit using the Proteus software and double click on the Arduino Uno (Atmega 328). Display the edit component window, creates the source object code (test1.ino.hex) file and upload it into the microcontroller. The uploaded file is compiled as a sixteen hexadecimal HEX file. Then a suitable simulation method was chosen to analyze and debug the design circuit. Third, the simulation begins by pressing the "run" button. Fourth, change the temperature, pressure and RH parameters and watch simulation results, then examine the influence of these parameters on the CO_2 concentration [13, 14]. Fifth, Check the memory data changes and CPU registers. The CPU Internal Memory CPU Registers and CPU SFR Memory data changes when the program is running respectively.

The circuit design and simulation for CO_2 concentration estimation was performed using Proteus professional (Version 8) and a Notebook Intel (R) Core (TM) i3 CPU, 2 GHz, and OS Windows 10 (64 bit) environment. Besides, the mathematical modelling for the computation of CO_2 concentration was performed using Arduino IDE (Version 1.8.8).

3. Results and Discussions

We have performed testing of our designed CO_2 concentration estimation circuit via simulation using Proteus software (refer figure 3) and Arduino IDE. Figure 5A and 5B depict the effect of pressure on CO_2 concentration of a user prompted to enter reference temperature. It can be observed that the CO_2 concentrations changed from 21.25% to 26.18% with a change in pressure from 21.53kPa to 26.52kPa with respective to referenced temperature (25°C). We have also observed that with the increase of pressure, the CO_2 concentration value increases in agreement with an earlier study [18].

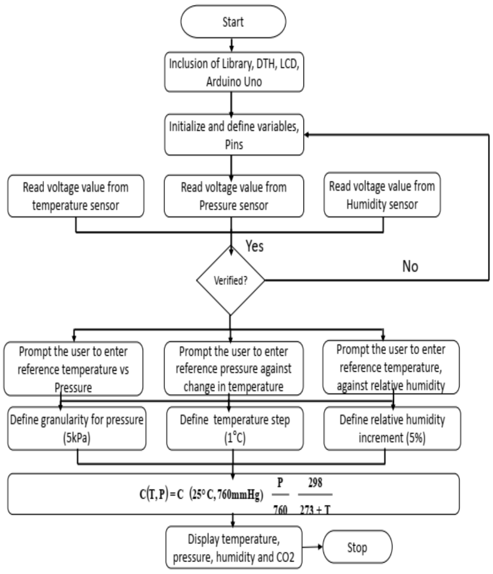

Figure 4. Procedure for the computation of carbon dioxide concentration based on temperature, pressure, and relative humidity.

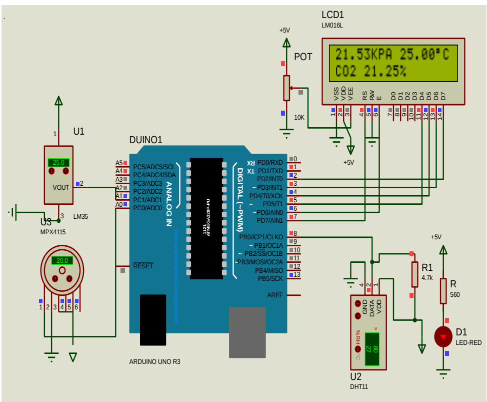

Figure 5(a). Result of CO_2 concentration user prompted to enter pressure with reference temperature.

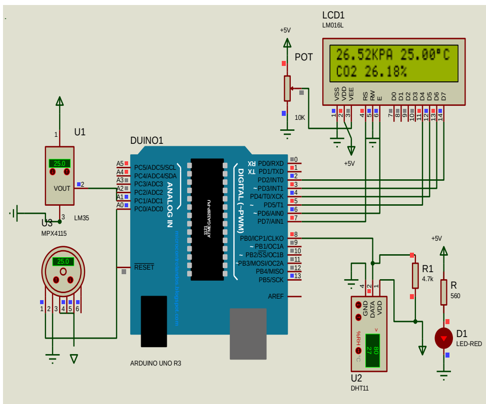

Figure 5(b). Deviation in CO_2 concentration user prompted to enter pressure.

Further, **figure 6** illustrates the effect of temperature on CO_2 concentration while keeping pressure constant (31.52kPa). It was observed that the CO_2 concentration changed with a change in temperature in a reciprocal manner. From Fig. 6 (A and B), it can be noticed that when temperature raises from 25ºC to 30ºC, CO_2 concentration dropdown from 31.11 to 30.60%. Besides, the deviation in CO_2 values was found less comparatively pressure.

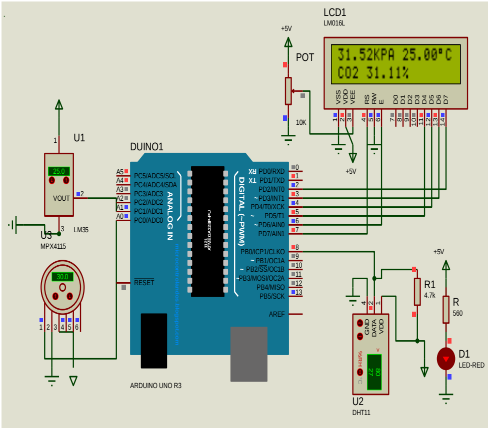

Figure 6(a). Result of CO_2 concentration user prompted to enter a temperature with reference pressure.

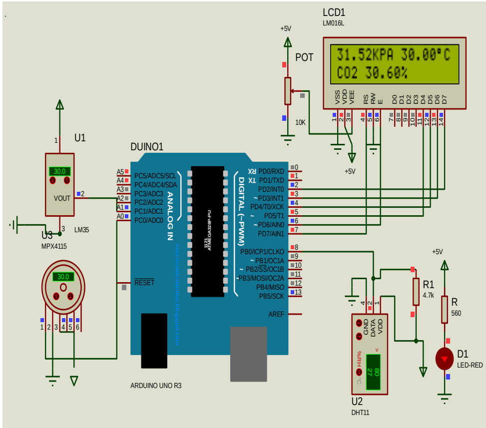

Figure 6(b). Deviation in CO_2 concentration user prompted to enter temperature.

Figure 7 reflects the behaviour of CO_2 values with a change in humidity. The temperature was set at 25ºC while relative humidity (RH) was fixed at 28%. We observed that with a change in humidity from 28% to 30%, CO_2 value changed from 6.26% to 9.39%. It reveals a change in CO_2 concentration depends upon RH. The effect of RH was verified with respect to change in water vapour pressure using (4) and (5).

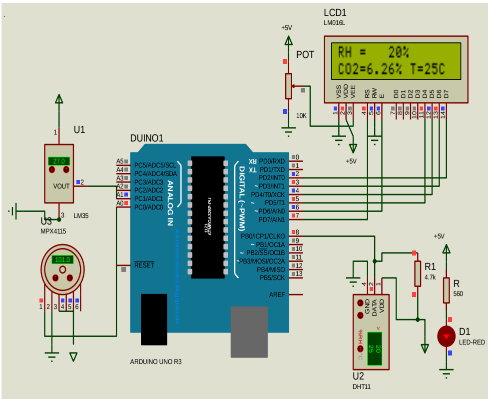

Figure 7(a). Result of CO_2 concentration user prompted to enter humidity with reference water vapour pressure.

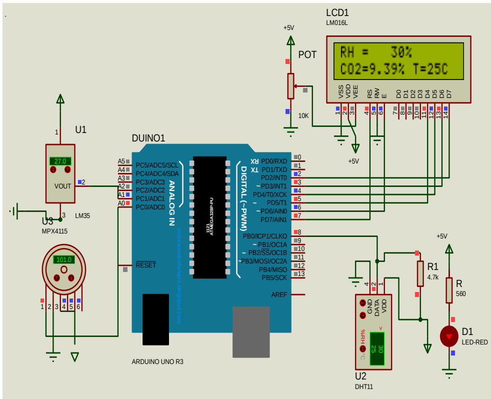

Figure 7(b). Deviation in CO_2 concentration user prompted to enter humidity.

4. Conclusion

This study presents a simulation study to verify the effect of pressure, temperature, and humidity on the CO_2 concentrations. A CO_2 estimation circuit was designed using pressure, temperature, humidity sensor. Thereafter, a mathematical modelling was performed into the Arduino IDE and to compute the CO_2 concentrations. We observed that CO_2 concentration changes drastically with the change in pressure, temperature and humidity. Hence, while developing the infrared CO_2 sensor, the pressure, temperature and humidity sensor should be integrated for the automatic adjustment of CO_2 concentration based on the current atmospheric parameters compared with manual in real time, which may possibly reduce the error in CO_2 reading causes by environmental factors.

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