IMPLEMENTATION OF GAS SAMPLING CHAMBER AND MEASURING HARDWARE FOR CAPNOGRAPH SYSTEM CONSIDERING THERMAL NOISE EFFECT AND TIME RESPONSE CHARACTERISTICS

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Abstract- **Most capnograph systems that can indirectly determine the partial pressure of carbon dioxide in the blood of a patient are based on NDIR(non-dispersive infrared) absorption technology. As such an NDIR gas analyzing method requires an optical absorption chamber and signal processing hardware. Accordingly, this paper designed and implemented an NDIR type CO_2 gas chamber while considering the time response characteristics and lamp chopping frequency. In addition, signal processing hardware using two infrared sources was implemented to reduce the thermal background effect. The gas chamber and signal processing hardware has been tested using temperature variation and human expiration experiment. The results showed that the system could produce a stable output signal and discerning CO_2 gas concentration curve similar to a typical capnogram.**

***Keywords* – NDIR, capnograph, optical gas chamber, thermal background effect**

I. INTRODUCTION

As a measuring method for a capnograph system that determines indirectly the level of pCO_2 in a patient's blood, the NDIR method is commonly used[1][2]. The structure of the optical chamber used in NDIR CO_2 gas measurement can influence the characteristics of the sensor output signal and time response. A better S/N is obtained with an optical chamber that is longer in length. However, a longer length leads to an increase in the CO_2 gas accumulated in the optical chamber and affects the time response for detecting the CO_2 concentration. Therefore, the appropriate chopping frequency and characteristics of the time response should be considered to obtain a normal capnogram when designing an optical chamber. Plus, a CO_2 gas sensor has a problem in that its output signal can drift due to the effect of outer thermal noises[3].

In this paper, the proper chopping frequency is determined based on the frequency spectrum of a typical capnogram. Thereafter, the optical chamber is designed considering the time response. A pre-amp and signal processing hardware for the measurement of the CO_2 gas concentration are also designed and implemented by adopting the technique of two infrared sources and a pyroelectric sensor to reduce the thermal background effect in the sample chamber[4]. The gas discharge time of the implemented chamber was then investigated. The designed gas chamber and signal processing hardware were tested using temperature variation and human expiration experiments. The results showed that the system could produce a stable output signal and good CO_2 gas concentration curve similar to a typical capnogram.

II. DESIGN AND IMPLEMENTATION OF CHAMBER AND SIGNAL PROCESSING HARDWARE

1) *Design of optical chamber*: The 4.3um wavelength component radiated from an IR lamp can be represented as a function of the CO_2 gas concentration and optical chamber length using Beer's law. A pyroelectric sensor output signal is decreased to the degree of the absorbed IR, and the CO_2 gas concentration can be determined based on the decreased sensor output signal. To obtain a high S/N for the sensor output signal, a longer optical chamber is more advantageous. However, if the optical chamber is too long, the time taken to discharge the CO_2 gas in the sample chamber is too slow, thereby resulting in a poor time response for variations in the CO_2 gas concentration. In addition, the positions of the CO_2 gas inlet and outlet are related to the effective length of the optical path for absorbing IR in the sample chamber. Therefore, unlike the conventional optical chamber structure in Fig. 1, the current study positions the inlet and outlet as in Fig. 2 to produce a good IR absorption for CO_2 gas. In addition, using the relation as in (1), the diameter of the outlet is made larger than that of the inlet for a fast inhaling speed in the sample chamber. Finally, the volume of the optical chamber is calculated so that the measured gas can be discharged during one chopping time, as in the following (2).

$$\upsilon_i = \upsilon_o \times \frac{A_o}{A_i} \tag{1}$$

$$V_c \le \frac{A_o \cdot \upsilon_o}{f_s} \tag{2}$$

where υ_i, υ_o : inhaling and discharging speed

A_i, A_o : cross areas of inlet and outlet

V_c : volume of optical path in sample chamber

f_s : optical chopping frequency

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Abstract

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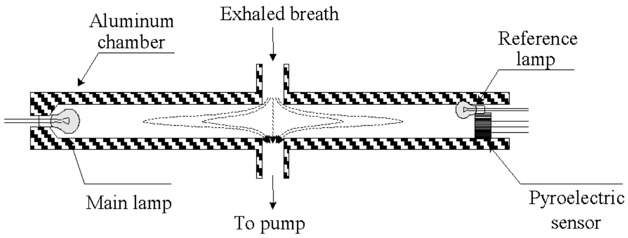


Fig. 1. Conventional optical absorption chamber structure using two IR sources

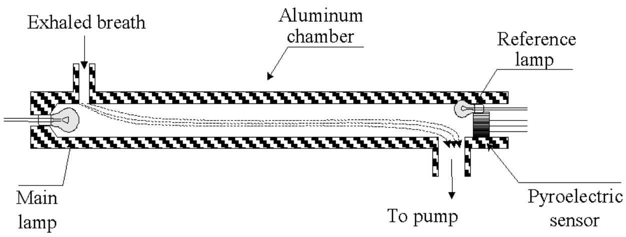


Fig. 2. Newly-designed optical absorption chamber structure

The chopping frequency of an IR lamp corresponds to the sampling frequency for the continuous measurement of the CO_2 gas concentration without aliasing. Based on a frequency analysis of practical capnograms acquired from commercial capnograph systems, the proper chopping frequency should be two times the bandwidth of the acquired capnograms. However, the electrical method for chopping IR light is limited to within 20Hz due to the thermal constant of an IR lamp.

2) *Sensing method using two infrared sources*: The sensing chamber using two IR ramps operates with the main lamp on the left side and the reference lamp on the right side, the phase difference for which is 180 degrees as in Fig. 3. Suppose that the sensor output signals induced by the main and reference IR lamps are affected by the same thermal noise effect, the output signal of the pyroelectric sensor can then be represented by the following (3), where I_1, I_2 are the intensities of the IR radiated from the main and reference lamps, irrespectively, and ΔI_c is the amount of absorbed IR from the main lamp.

$$\begin{aligned} v_o &= \eta[(kI_1 - \Delta I_c + n)\cdot u + (I_2 + n)\cdot \bar{u}] \\ &= \eta(kI_1 - I_2 - \Delta I_c)\cdot u + N \end{aligned} \tag{3}$$

Where v_o : sensor output component,

k : attenuate coefficient

η : sensor responsivity

$$u = \begin{cases} 1 & \text{if a main lamp is active} \\ 0 & \text{if a main lamp is inactive} \end{cases}$$

$$\bar{u} = \begin{cases} 1 & \text{if a reference lamp is active} \\ 0 & \text{if a reference lamp is inactive} \end{cases}$$

N : DC and low frequency component

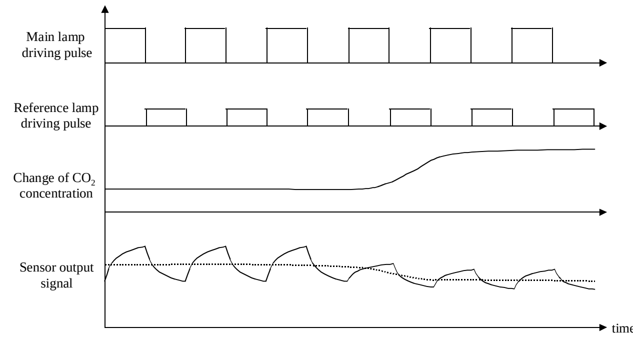


Fig. 3. Sensor output signal variation according to change in CO_2 gas concentration

After the sensor output signal, v_o in (3), passes through a narrow bandpass filter, the N term, which includes thermal noise at a low frequency, is eliminated as in (4).

$$v_{BPF} = \eta(kI_1 - I_2 - \Delta I_c)\cdot u \tag{4}$$

Hence, if the intensity of the reference lamp is adjusted to $I_2 = kI_1$, a stable signal resulting from just the variation in the CO_2 gas concentration can be obtained.

3) *Signal processing circuit for CO_2 gas concentration*: The detection circuit for the CO_2 gas concentration is composed of a lamp driving circuit and sensor signal-processing circuit as in Fig. 4. The two lamps comprising the lamp driving circuit operate alternately with a phase difference of 180 degrees. The intensity of the reference lamp is also variable. A second-order bandpass filter is used as the first preamplifier to magnify the sensor signal from the CO_2 optical chamber. Then a fourth-order Chebysev bandpass filter is used to extract just the signal component using the chopping frequency from the amplified signal. A multiplier then doubles the filtered signal frequency, and a CO_2 gas concentration signal with a high S/N is produced through a fourth-order MFB(multiple feedback) lowpass filter. Finally, the use of 240×64 graphic LCD makes it easy to continuously observe and measure the CO_2 gas waveform.

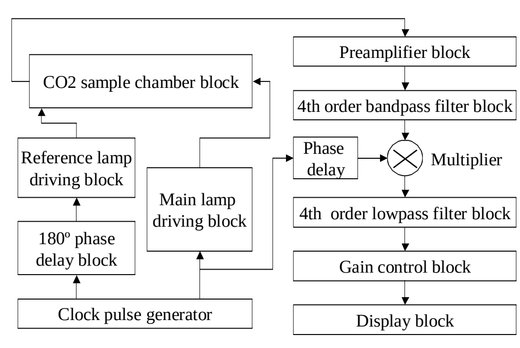
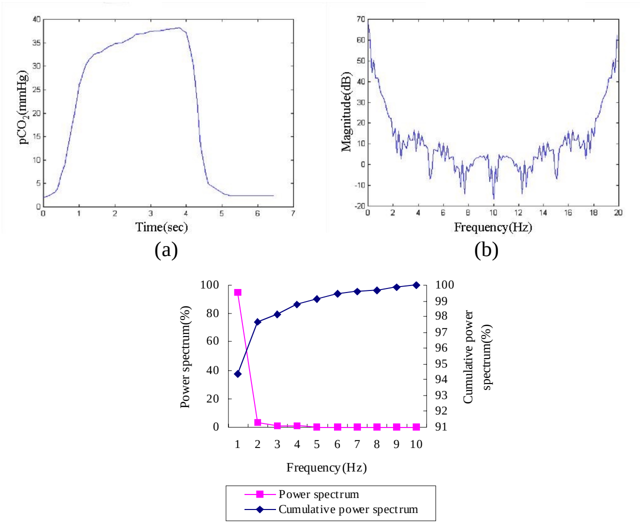


Fig. 4. Overall block diagram for CO_2 gas concentration measurement circuit



(c)

Fig. 5. (a) Practical capnogram, (b) its power spectrum and (c) distribution of power spectrum for each frequency

III. Experimental results

Through the frequency analyzing typical capnograms, as in Fig. 5.(a), it was verified that more than 95 percent of the total energy spectrum was localized within a bandwidth of 0～5Hz as in Fig. 5.(b) and 5.(c). Based on this result, the chopping frequency was selected to be 20Hz in consideration of the thermal constancy of an IR lamp. Thereafter, the volume of the chamber was determined so that the time required to discharge the gas in the optical chamber was shorter than the period of IR lamp chopping, and the optical length of each chamber was different. Fig. 6 shows the implemented optical chambers with different volumes, and Fig. 7 shows the results of the gas discharge time for each chamber. In Fig. 7, for a pump with an inlet speed of 2 *l*/min, the investigation of the implemented optical chambers showed that all the chambers satisfied the condition that the discharge time was shorter than a chopping period of 50msec. Furthermore, to examine the effect of thermal noise on the implemented capnograph system, the experimental environment shown in Fig. 8 was used. An increase in the surrounding temperature of the optical chambers was tested using a single IR source and two IR sources for 100 seconds. As illustrated in Fig. 9.(a), the result for the single IR source type chamber showed that the output signal was increased by a voltage of 1.2 within 100 seconds. However, in the two IR source type chamber, the change in the output signal was remarkably reduced, as in Fig. 9.(b). Fig. 10.(b) shows a stable and typical capnogram resulting from the continuous measurement of a normal male adult using the implemented optical chamber and electronic hardware.

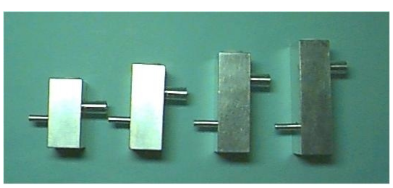


Fig. 6. The implemented optical absorption chambers

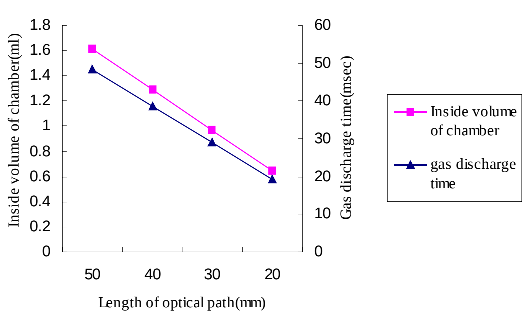


Fig. 7. Calculated values of inside volume and gas discharge time for implemented optical absorption chambers

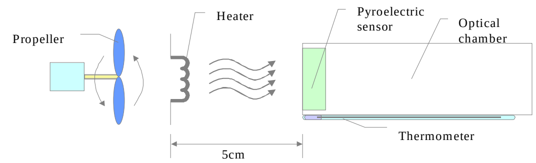
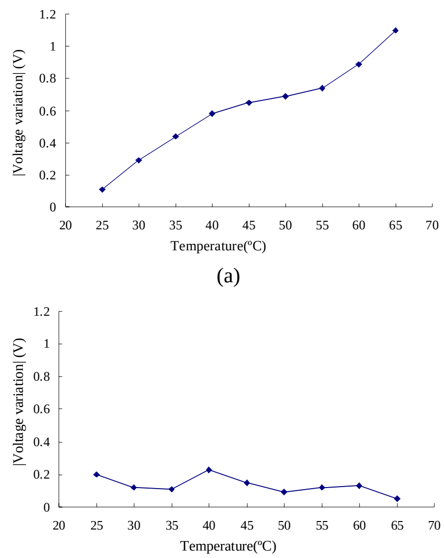


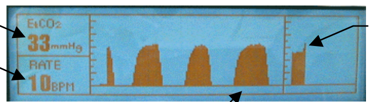
Fig. 8. Experimental apparatus for varying surrounding temperature of the optical chamber



(b)

Fig. 9. Experimental results (a) for one IR source sensing method and (b) two source method

(a)



(b)

Fig. 10. (a) Experimental system using implemented sensing circuit and designed chamber and (b) measured CO_2 concentration curve for male adult's expiration under normal conditions

IV. CONCLUSIONS

An NDIR absorption chamber for measuring the CO_2 gas concentration in a capnograph system was designed considering a high IR absorption and the time response characteristics for the gas discharge. An optical chamber and signal processing hardware were designed and implemented by applying a two IR source type sensing method to reduce the effect of thermal noise. For the implemented optical chamber, the gas discharge time was shorter than the IR lamp chopping period. The results of temperature variation and human expiration experiments, demonstrated that the proposed system could produce a stable output signal and a discerning CO_2 gas concentration curve similar to a typical capnogram.

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