Sensor Control Unit Design for a Photoacoustic Indoor Multi-Gas Monitor

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Abstract - Anesthetic gaseous components are necessary to be evaluated in hospital facilities, especially in surgical pavilions. Exposure to anesthetic gases in the health sector, whether in the operating room, recovery room, or in the context of outpatient clinics, may entail a health risk for the personnel exposed. Although health care workers are exposed to much lower anesthetic concentrations than the patients, this exposure often extends over many years. Personnel often indicate fatigue and headaches, especially when occupational hygiene conditions are inadequate. The decisive factors as concerns, the adverse health effects of exposure to anesthetic gases, are mainly the type of gases used, the length of exposure, and the gas concentrations. This paper aims to describe an attempt (successful) to design a sensor control unit in order to improve photoacoustic instrumentation.

I. Introduction

Occupational exposures to anesthetic gases involve concentrations much smaller than those administered to patients in surgery. The main criteria for assessing exposure to anesthetic gases are the atmospheric exposure limits, which are not yet harmonized Europe-wide. In many countries (in particular, Germany and Switzerland), these values are given in the official list of occupational exposure limits. In France, a Ministry of health circular sets the exposure limits applicable for the anesthesia maintenance phase. There are various techniques for measuring anesthetic gas concentrations in the air:

1) Direct-reading systems;
2) Air sampling with equipment such as adsorbent tubes or cuffs, followed by analysis using gas chromatography or an infrared technique;
3) Diffusion sampler and analysis.

Considering the variation range of the parameters affecting exposure to anesthetic gases, air monitoring should be preferred to other methods of assessing exposure in the workplace. The most commonly employed model for describing the photoacoustic effect in condensed samples was developed in the 1970s by Rosencwaig and Gersho. Applying Beer's Law with radiation intensity I_0 and optical absorption coefficient β:

$$dI = -\beta I dx \Rightarrow I = I_0 e^{-\beta x} \quad (1)$$

Suppose the incident radiation is modulated with frequency ω. Then the incident intensity is given by:

$$I' = \frac{1}{2} I (1 - \cos \omega t) \quad (2)$$

The sample and the gas must each satisfy the heat-diffusion equation, which for the case of the sample is given by:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} - \frac{\beta \sigma_{ri} I'}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} - \frac{\beta \sigma_{ri} I_0}{2k} e^{-\beta x}(1 - \cos \omega t) \quad (3)$$

where σ_{ri} is is the probability of radiationless transition, and thermal diffusivity $\alpha = \frac{k}{\rho c}$

where k is thermal conductivity of the sample, ρ is the density, and c is the specific heat. Rosencwaig and Gersho determined the following equation for temperature in the surrounding medium as a function of both position and time:

$$T^{ac}(x,t) = e^{-ax}\left[\theta_1 \cos(\omega t + ax) - \theta_2 \sin(\omega t + ax)\right] \quad (4)$$

where the complex temperature amplitude $\theta = \theta_1 + i\theta_2$, and the thermal diffusion coefficient $a = \sqrt{\frac{\omega}{2\alpha}}$.

The equation describes a periodic wave of temperature that propagates through the medium surrounding the sample. The temperature fluctuation described by this equation is the cause of the pressure waves that are detected. Since the e^{-ax} causes the wave to decay away from the sample, the sensor should be located within the thermal diffusion length $\mu = \frac{1}{a} = \sqrt{\frac{2\alpha}{\omega}}$ in order to maximize the strength of the acoustic signal. Surprisingly, modern photoacoustic analysis has not deviated far from Bell's original "chopped light" setup, apart from the introduction of lasers and microphones. A typical photoacoustic experiment consists of a laser incident upon a chamber, which is modulated with a physical "chopper" or some other method of precisely pulsing the light. The acoustic signal is measured with either a microphone or piezo sensor depending on the frequency. Frequencies of applied light from microwaves to X-rays can be used, but lasers or xenon lamps tend to be the most common. Sensitivity is of great importance in any type of photoacoustic measurement, so a chamber containing a sample for analysis must be well insulated from outside noise and vibration. The photoacoustic effect due to surrounding materials such as the chamber itself must also be minimized - even the chamber itself will demonstrate some amount of photoacoustic emission, and this effect must be taken into account by the experimenter. Modern photoacoustic experiments commonly employ chambers with cylindrical or spherical symmetry in order to take advantage of acoustical resonances. In this case, a standing wave is formed by tuning the applied laser to the resonance frequency of the chamber. This resonance amplifies the sound signal and allows it to be more easily detected.

II. Design

Fig. 1 illustrates a commercial photoacoustic instrumentation used for anesthetic gas measurements; while fig.2 shows clamps from which signal (fig.3) is taken for analysis in order to design a new sensor control board according to the overall scheme illustrated in fig.4.

Fig. 1 Partial view of a photoacoustic instrumentation

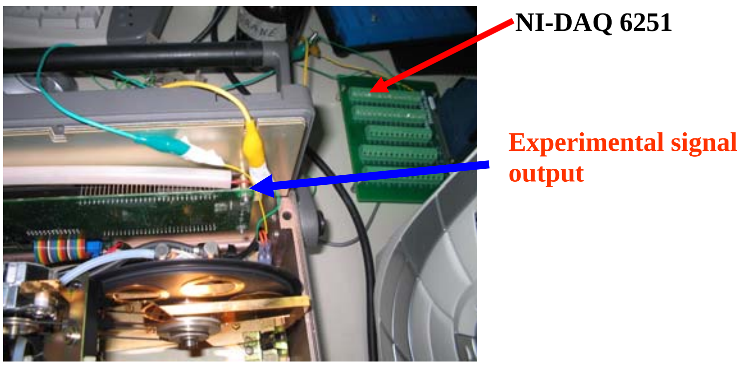

Fig. 2 Signal acquisition procedures

As indicated, blocks relative to sensor units and impedance adaptation buffers are included in the scheme for completeness but, they are not really included in the board. After successive treatments by means of labview virtual instrumentation, a board is designed as demonstrated in fig.5.

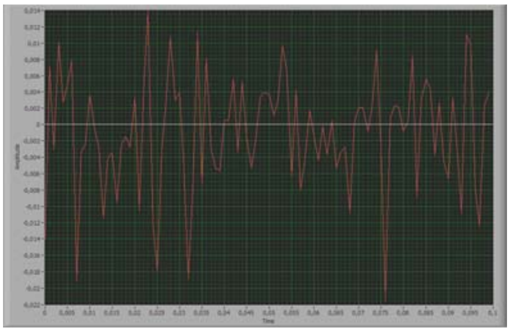

Fig. 3 Extracted signal

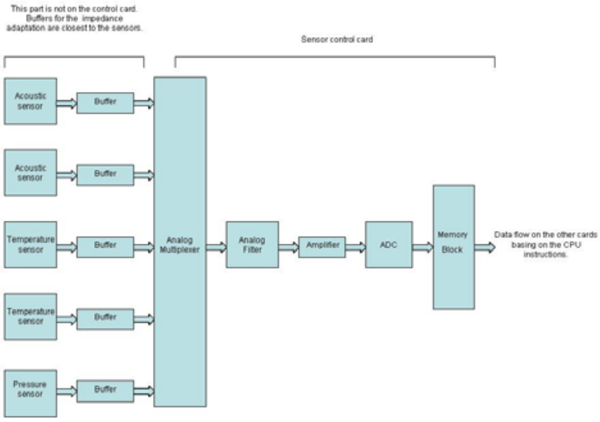

Fig. 4 Block diagram of sensor board

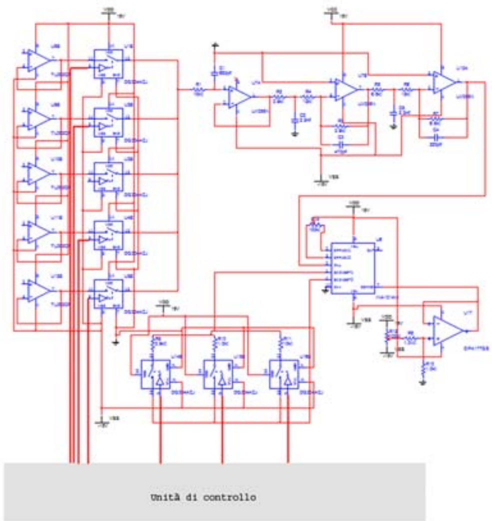

Fig. 5 Designed sensor control board

III. Results and conclusion

An INA101AM has been used to design an amplification unit since for the purpose of this research a kind of precision is requested. This IC is characterized by the following parameters: low thermal derive - 0.25mV/°C max, low offset voltage - 25mV max, low nonlinearity - 0.002%, low noise, 13nV/$\sqrt{Hz}$. Fig. 6 and fig. 7 show an example of results produced from characterizing the sensor control board designed in order to improve performance of this particular instrumentation. INA101 allows to set gain connecting a resistance R_G so that the gain G is given by the relationship:

$$G = 1 + \frac{40k\Omega}{R_G} \qquad (5)$$

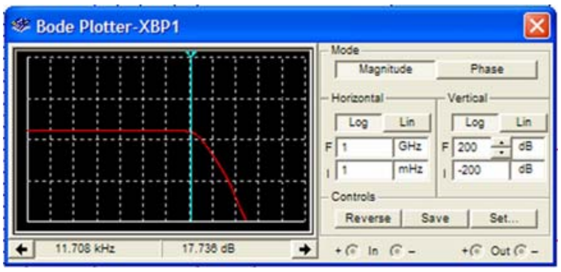

Fig. 6 Amplitude bode diagram

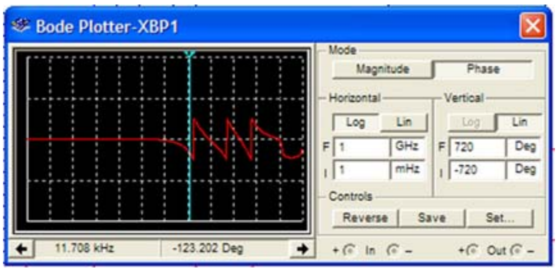

Fig. 7 Phase bode diagram

The new sensor control board has been made as simple as possible, so that CPU has no constraints in processing measured data. This choice allows to reduce production costs of this kind of instrumentation. A further question has been faced, concerning the design of a new chamber capable of measuring indoor gas in surgery rooms. The major advantage of this chamber (fig. 8) consists in a double light source, instead of one, according to commonly used photoacoustic apparatus, that increases the accuracy of measurements by allowing a double analysis of the same gas. This asset also increases the speed of analysis in acquiring a gas when a multi-sampling facility is adopted.

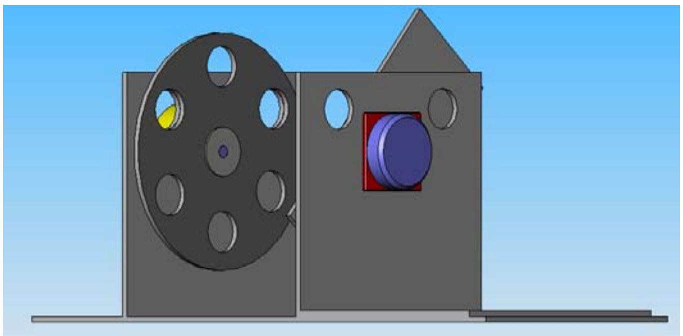

Fig. 8 Rendering of designed chamber

In order to control and to move correctly the two steppe motors, namely, one for the chopper wheel and the other for the optical filter carousel, an appropriate electric circuit has been realized and tested for this purpose, as indicated in fig. 9. Finally, it is possible to test the chamber for a real case. Since many perfumes [9] contain solvents (e.g. phthalates), that are similar to thoses recovered in surgery rooms, different sessions of measurements have been carried out according to tab.I, where the perfume spectrum is converted in voltages. Different spectra converted in voltages agree with the perfume composition of different producers.

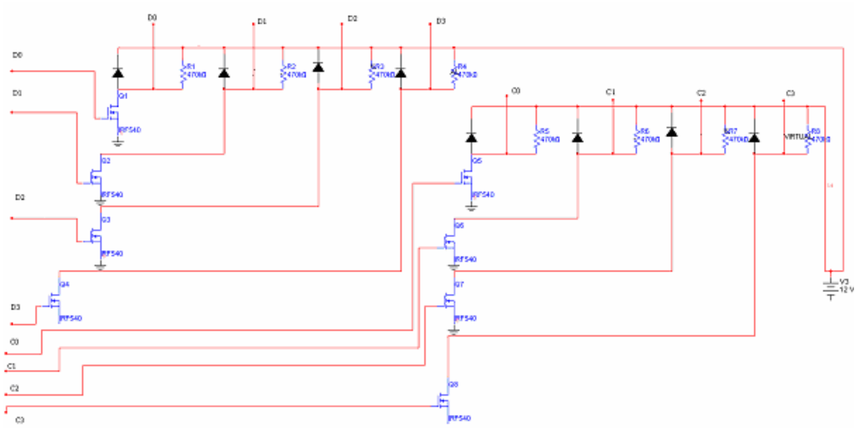

Fig. 9 Electric circuit for controlling two stepper motors

	Vpp [mV]	**Vavg** [mV]	**Vrms** [mV]	**Freq** [Hz]	**Period** [ms]	**Duty-cycle**
No perfume	***170,3***	***370,3***	***377,4***	***4,301***	***232,5***	***57%***
perfume						
1	154,700	367,800	373,800	4,167	240,000	55,20%
2	155,200	380,200	375,800	4,100	238,000	54,60%
3	154,630	369,800	376,800	4,183	243,000	55,40%
4	155,110	365,800	377,800	4,210	237,000	55,40%
Average	154,910	370,900	376,050	4,165	239,500	55,20%
Std. dev.	0,24829418	5,55247692	1,47901995	0,04055244	2,29128785	
Conf. int.	0,00778486	0,17408897	0,04637229	0,00127146	0,07183964	

Tab.I Experimental measurement results

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