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Assessing Multiple Myeloma Using Photoacoustic Spectrum Detection Method

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Summary:
This study uses photoacoustic detection spectroscopy to develop a spectroscopic detection system and evaluate the feasibility of multiple myeloma. At the current stage, circuit board development has been completed and a synchronized photoacoustic detection platform for finger and test tubes has been established. This study found that a single-wavelength photoacoustic detection platform can be used to measure blood oxygen saturation. Furthermore, it was discovered that there is a corresponding relationship between the photoacoustic amplitude and the cysteine concentration. In the future, the cysteine solution concentration can be derived from the photoacoustic amplitude detected by the system.

Keywords: multiple myeloma, photoacoustic microscopy (PAM), photoacoustic (PA)

Introduction

Multiple myeloma (MM) is the second most common tumour of the hematologic system, affecting 488,000 people worldwide [1]. The treatment of MM cancer patients poses a significant challenge for physicians. However, continuous monitoring of progression and its effects on medications can be a helpful observational indicator for the treatment of multiple myeloma.

The principle of photoacoustic effect is that when an object absorbs laser energy, it generates ultrasonic waves. When the excited ultrasonic signals and the echo of the photoacoustic signal is detected using piezoelectric elements, the influence of light scattering is theoretically avoided. There are no concerns about radiation such as X-rays or CT scans, and the images are generated. Previous studies have shown that photoacoustic microscopy (PAM) can non-invasively measure and detect the reduced vascularization around hypoxic blood in patients with multiple myeloma using photoacoustic technology [2,3,4]. This project aims to implement a non-invasive photoacoustic detection system to evaluate patients with diabetes mellitus (DM) and multiple myeloma using urine, ex vivo blood, and finger vasculature. The goal is to observe whether simultaneous control of blood glucose can achieve therapeutic effects for multiple myeloma.

The photoacoustic detection system utilises an FPGA chip to control a laser with a wavelength of 638 nm for irradiation. When the samples in the test tube and the finger are irradiated with laser light, a photoacoustic effect occurs sequentially. The system uses piezoelectric ceramic elements to receive the photoacoustic signals from the samples, followed by three-stage amplification circuits for signal amplification, and uses a data acquisition system (DAQ) to capture the photoacoustic signals.

Method

In the laser-induced photoacoustic (PA) process, the acoustic signal, as described in reference [5], is generated due to the thermal expansion of the sample after absorbing optical energy. In this case, blood vessels act as the absorber, and we can obtain the PA signal:

$$P = A(\varepsilon_{HbO2}C_{HbO2} + \varepsilon_{HbR}C_{HbR}) \quad (1)$$

ε_{HbO2} and ε_{HbR} represent the absorption of oxyhemoglobin and hemoglobin, C_{HbO2} and C_{HbR} are for the blood oxygen concentration, as in Eq. (1), let red is $[\mathrm{HbO2}]$, $Green$ is$[Hb]$, eq. (1) can be simplified as follows:

$$P = (A_1C_{red} + A_2C_{green}) \quad (2)$$

whileλ is 658 nm:

$$A_1 = A \times \varepsilon_{HbO2} = 0.07A$$

$$A_2 = A \times \varepsilon_{HbR} = 0.81A$$

When the blood oxygen saturation is 99%, as in, e.g. (2)

$$P = (A_1C_{red} + A_2C_{green})$$

$$= (A_1 \times 0.99R + A_2 \times 0.01R)$$

$$= (0.0693 \times AR + 0.081 \times AR) = 0.0774AR$$

When the blood oxygen saturation is 97%, as in, e.g.

(2)

$$P = (A_1 \times 0.97R + A_2 \times 0.03R)$$

$$= (0.0679 \times AR + 0.0243 \times AR) = 0.0922AR$$

The constant AR is denoted as C, and the table below shows the signal size of P at various concentrations.

Tab. 1. 90~99% SO_2 V.S. SIGNAL SIGNAL SYSTEM P

Measure Signal	SO_2									
	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%
P	0.144C	0.137C	0.129C	0.122C	0.114C	0.107C	0.099C	0.092C	0.084C	0.077C

The current system architecture measures the obtained signals, defining the maximum amplitude in the signal as peak-to-peak intensity. As shown in Fig. 1., $M_{pp(N)}$ represents the peak-to-peak value, which is the maximum value minus the minimum value in the signal [6].

$$M_{pp} = M_{max} - M_{min} \quad (5)$$

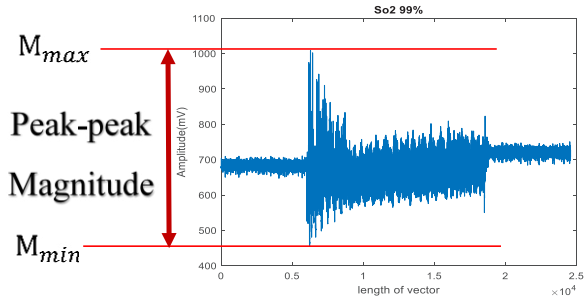

Fig. 1. Peak to peak voltage

Results

After experimental testing, the sensitivity of the photoacoustic signal at six different positions on the meshed piezoelectric ceramic plate was examined. Position B exhibited a more pronounced sensitivity, as shown in Fig. 2, where the values at Position B stand out. Following statistical analysis, Table 9 clearly indicates that the average value is around 3.09 mV, with a standard value range of approximately ±5.42 for position B. It can be observed that the response of Position B to the photoacoustic effect is more significant.

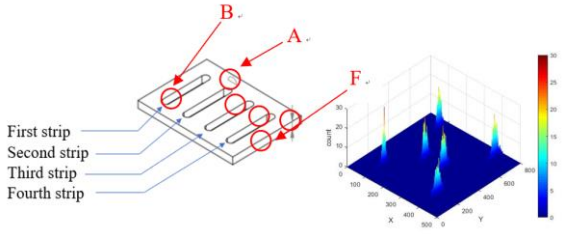

Fig. 2 Piezoelectric ceramic plate schematic and photoacoustic signal feedback distribution diagram

Tab. 2: Photoacoustic response of laser at six different positions on the meshed piezoelectric ceramic plate

650nm	A	B	C	D	E	F
mean	3.09	3.09	3.09	3.09	3.09	3.09
$\pm sd$(mV)	±4.57	±5.42	±5.09	±5.27	±4.72	±5.26
532nm	A	B	C	D	E	F
mean	3.09	3.09	3.09	3.09	3.09	3.09
$\pm sd$(mV)	±5.82	±6.48	±6.03	±6.00	±6.15	±6.00

The development of the optoacoustic platform has been completed in research, and the first version of the hardware prototype has been developed and released. Modifications were made to address issues from the previous version, and a second complete version was introduced. Using the hardware prototype of the first version, along with software development and multiple improvements in mechanical design, the entire optoacoustic platform system was integrated. The development included finger detection and test tube sample detection systems. The final product is shown in Fig. 3, with Fig. 4 depicting the finger measurement area, Fig. 5 showing the test tube measurement area, and Fig. 6 illustrating the system's operating interface.

Fig. 3. Completed design of the optoacoustic platform