

Photoacoustic sensor of Temperature with Linear-shaped light source

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Abstract A method of temperature measurement based on photoacoustic technique with its noninvasive, real-time, high precision is a new type technology. A cylindrical lens was applied to improve the signal to noise ratio of the detector system in this paper. Then, the relation of photoacoustic signal and temperature were discussed, the corresponding image was obtained. The result indicated that the photoacoustic pressure amplitude presented a good linear relationship at temperature range from 20 °C to 50 °C. The study demonstrated that the photoacoustic temperature measurement approach is feasible.

1. Introduction

A temperature measurement method with real-time, noninvasive and accurate is necessary for biomedicine research, especially on the process of photothermal therapy and cooling therapy. At present, some promising techniques of temperature measurement have been developed, including infrared thermography, ultrasonography, and MRI techniques. Infrared thermography method is the real-time temperature measurements with the accuracy of 0.1°C. However, this method is only applicable from surface to superficial of tissue [1]. Ultrasonography is capability of monitoring in real time with good resolution and has relatively low cost, but lacks of high accuracy on temperature measurement [2-5]. MRI is able to provide the images with high resolution and contrast. However, it has limitations associated with long acquisition time and high cost [6].

Laser photoacoustic technique for monitoring temperature is a new type technology with its noninvasive, real time, high precision. Photoacoustic technique has applied on monitoring the process of heating, coagulation, freezing, hypothermia and cooling in biological tissues with its high contrast and resolution [7-11]. But the many applications have not considered the effects of photoacoustic signal caused by irradiated by the pulsed laser. In our study, a cylindrical lens was applied in photoacoustic system. Photoacoustic signal with and without a cylindrical lens were compared to study, and then cylindrical lens was used to change the way of pulsed laser irradiation to improve the signal



to noise ratio (SNR) of the photoacoustic imaging system. Finally, vitro pork liver was used for experiment of photoacoustic monitoring temperature on the best SNR of photoacoustic system.

2. Theoretical background

Laser optoacoustic imaging technique is based on thermoelastic mechanism of pressure wave generation. Pressure of thermoelasticity rises with absorbing non-scattering medium upon stress-confined irradiation conditions is defined as [12].

$$P(z) = (\beta c^2 / C_p) \mu_a F(z) = \Gamma \mu_a F(z) = \Gamma \mu_a F_0 e^{-\mu_a z} \quad (1)$$

where, β [1/°C] is the thermal expansion coefficient; c [cm/s] is the speed of sound; C_p [J/g·°C] is the heat capacity at constant pressure; μ_a [1/cm] is the absorption coefficient; $F(z)$ [J/cm²] is the laser fluence; F_0 [J/cm²] is the incident laser fluence; $\Gamma = \beta c^2 / C_p$ is the Grüneisen parameter. The factor $e^{-\mu_a z}$ represents exponential attenuation of the optical radiation in the medium.

According to equation (1), optoacoustic pressure is proportional to the Gruneisen parameter, fluence, and absorption coefficient of the medium. The exponential slope of optoacoustic signal determines by the absorption coefficient of a nonscattering medium.

For high scattering tissues, the exponent is determined by the effective attenuation coefficient μ_{eff} [1]:

$$\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu'_s)} \quad (2)$$

where $\mu'_s = \mu_s(1-g)$ [1/cm] is the reduced scattering coefficient, μ_s [1/cm] is the scattering coefficient, and g [dimensionless] is the anisotropy factor of the tissue.

Thus, Optoacoustic pressure distribution in a biological tissue with attenuation coefficient μ_{eff} can be expressed:

$$P(z) = \Gamma \mu_a k F_0 e^{-\mu_{eff} z} \quad (3)$$

where k is the parameter resulting from multiple scattering in tissue and is dependent on the absorption and scattering coefficients.

Since the Grüneisen parameter of tissue is linearly dependent on temperature in the temperature range from 20 to 52 °C [13].

$$\Gamma = A + BT \quad (4)$$

where A and B are constants and T is the temperature. one can rewrite equation (3) as follow:

$$P(z) = [A + BT(z)] k \mu_a F_0 e^{-\mu_{eff} z} \quad (5)$$

Using this equation one can obtain:

$$T(z) = C + DP(z) / P(z)_{T=T_0} \quad (6)$$

where $T(z)$ is the temperature distribution in tissue, $P(z)_{T=T_0}$ is optoacoustic pressure profile recorded at initial temperature T_0 (before heating). C and D are parameters that are dependent on tissue properties. Therefore, the temperature distribution during hyperthermia process will be reconstructed through recording and analysing the temporal optoacoustic pressure profile .

3. Materials and Method

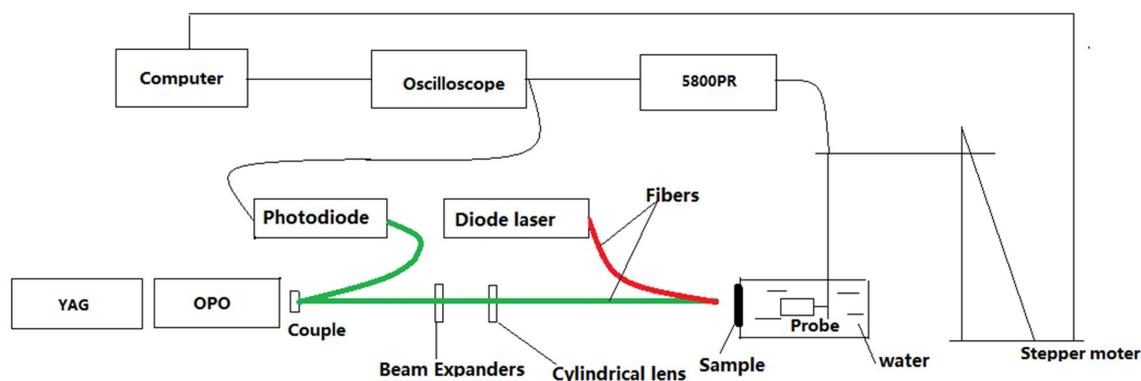


Fig 1. experimental setup

3.1 sample

Fresh excised pork liver with 60mm x 50 mm x 25mm was used for the experiments.

3.2 system

The experimental setup was shown on Fig 1. Nd:YAG laser with wavelength 532nm, pulse width 5ns, repetition frequency 10Hz was used for optoacoustic wave generation. Diode laser with wavelength 810nm was used for treatment heat source.

The light emitted from Nd:YAG laser was divided into two beams. One beam was received by the photodiode, and the signal was displayed on the digital oscilloscope which connected with the computer. The other beam was irradiated on the sample with linear spot after penetrating the beam expanders and cylindrical lens. The thermocouples was inserted the place where the continuous laser emitted from Diode laser irradiated in the center of a line-shaped light. The sample and water were separated by transparent plastic wrap. The ultrasonic signals were detected by ultrasound transducer (5MHz) on the other side of irradiated surface. The signals received by ultrasound transducer were transmitted to ultrasonic pulse generator/receiver (5800PR) and then displayed on the digital oscilloscope. In addition, the stepper motor was applied to realize scanning imaging of sample.

3.3 method

In case of keeping the same conditions during the experimental, the intensities of photoacoustic

signals of the pork liver with and without a cylindrical lens were detected at the same environment with 16 °C. And then, the signals of two-dimensional scanning of the pork liver without and with a cylindrical lens were scanned, respectively. Then, the 2D images were reconstructed by the signal, which obtained from without and with cylindrical lens.

Finally, the pork liver were heated intermittently when the thermocouple temperature reached at 20 °C, 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, respectively. During this process, the thermocouple temperature changed slightly with 2D scanning by the stepper motor. All above scans are along the line-shaped light with 0.1mm scanning steps and 27mm scanning length.

4. Results

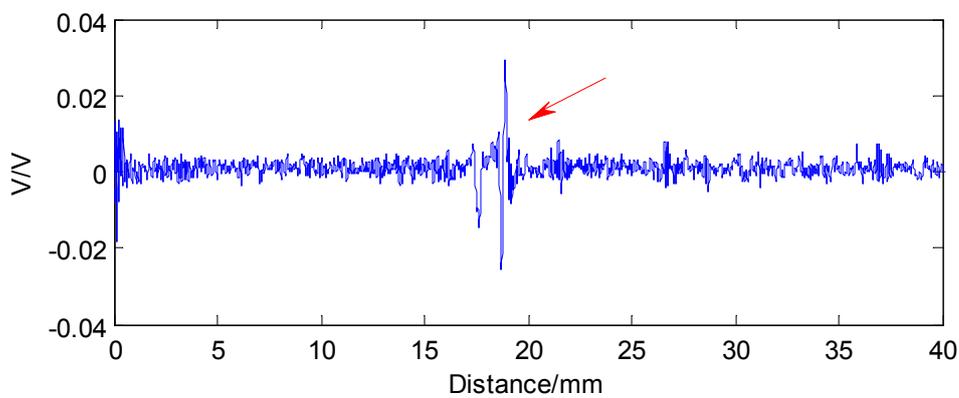


Fig 2. photoacoustic signal of without cylindrical lens

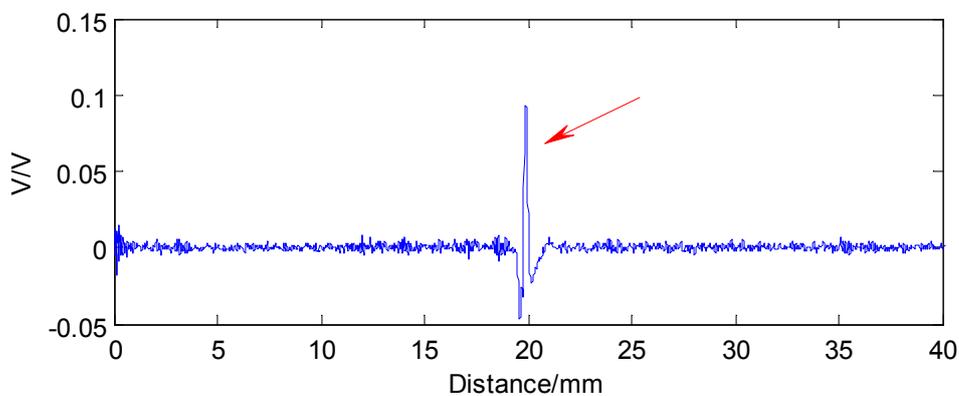


Fig 3. photoacoustic signal with cylindrical lens

The case without and with cylindrical lens were displayed in Fig 2 and Fig 3, respectively. The photoacoustic signal were shown by the arrow. The SNR of photoacoustic signal without cylindrical lens is 12.835, while it is 53.289 with cylindrical lens . The results indicated that the signal to noise ratio of the photoacoustic system will be greatly improved and the quality of photoacoustic images also will be obtained with the cylindrical lens.

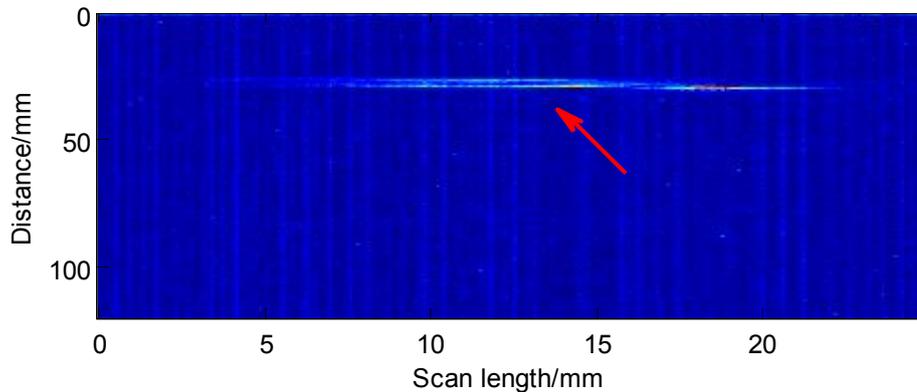


Fig 4. 2D scanning image of the pork liver without cylindrical lens(surface light source) at 16 °C.

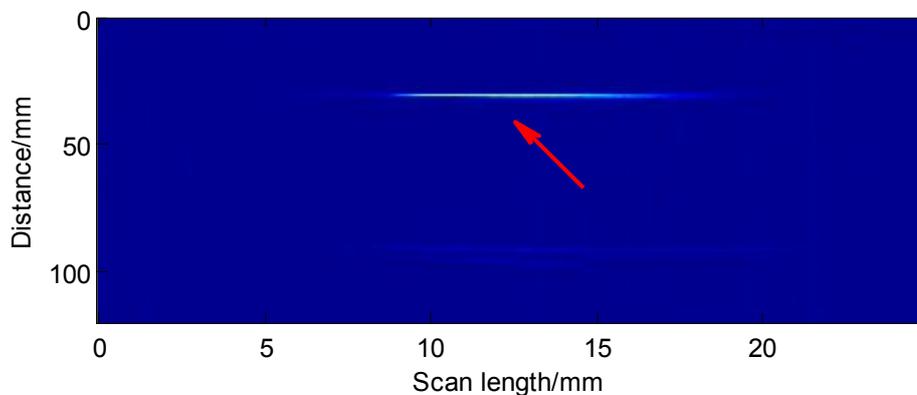


Fig 5. 2D scanning image of the pork liver with cylindrical lens(surface light source) at 16 °C.

The case 2D scanning image of the pork liver without and with cylindrical lens (surface light source) at 16 °C were displayed in Fig 4 and Fig 5, respectively. The photoacoustic signals were shown by the arrows. X-axis represents scanning length, and Y-axis represents the distance from the ultrasonic transducer to the detected signal. The light distribution is more concentrated and photoacoustic signal is stronger with cylindrical lens. The results showed that the way of line-shaped light irradiation with cylindrical lens with its focusing function has higher utilization efficiency of source in the same laser energy, compared with the way of being irradiated by large area uniform light, the defect of insufficient light intensity in per unit area in the case of uniform illumination was overcome in the way with cylindrical lens.

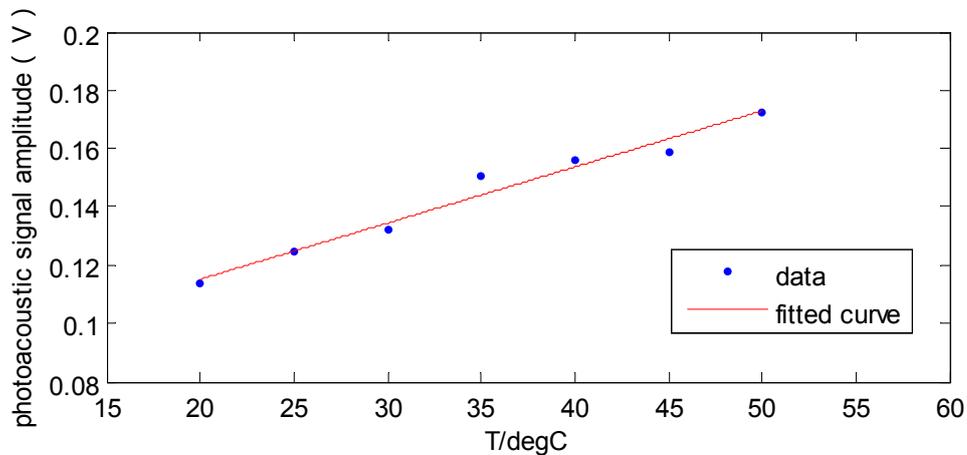


Fig 6. photoacoustic signal amplitude versus temperature

The linear light was uniform in a small enough area using the cylindrical lens. The photoacoustic signal amplitude versus temperature was displayed in Fig 6. Concretely the maximum photoacoustic signal amplitude was extracted from 2D scanning data sets of the pork liver with cylindrical lens (surface light source) at 20 °C, 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, respectively. The values were 0.1137 V, 0.1245V, 0.1320V, 0.1503V, 0.1562V, 0.1588V, 0.1726 V. From the fitted curve, we can see that with the increasing temperature, the photoacoustic signal that excited by the same laser energy becomes stronger with the temperature from 20 °C to 50 °C.

5. Conclusion

In this paper, photoacoustic signal with and without a cylindrical lens were compared to study, and then fresh vitro pork liver was used for experiment of photoacoustic monitoring temperature. The results demonstrated that the SNR of photoacoustic signal can be improved by cylindrical lens. The light distribution is more concentrated and photoacoustic signal is stronger with cylindrical lens. The temperature and the photoacoustic pressure amplitude presented a good linear relationship at temperature range from 20 °C to 50 °C. The photoacoustic technique monitoring temperature can potentially be a valuable method for temperature measurement.

Acknowledgment

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