Quantitative effect of temperature to the absorbance of aqueous glucose in wavelength range from 1200nm to 1700nm

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Abstract: In this paper, to find the quantitative errors of aqueous glucose induced by the temperature change at every wave point ranging from 1200nm to 1700nm, the calibration curve is calculated and shown. During the measurement the temperature varies from 30□ to 40□, at a 2□ interval, and aqueous glucose concentration ranges from 100mg/dL to 500mg/dL, at a interval of 100mg/dL. The absorption of aqueous glucose decreases with the increasing of temperature, also the absorbance decreases. In addition, only 1□ change in the temperature induces about -7×10^{-3} and -4×10^{-3} errors in the absorbance of the aqueous glucose at the wavelength of 1550nm, 1610nm respectively. So the examined result should be correct according to the data read from the calibration curve if the temperatures of modeling and measuring are not uniform. Using this method, the error caused by the temperature change can be reduced even eliminated.

OCIS code: 250.0250 (Optoelectronics); 300.0300 (Spectroscopy)

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1. Introduction

Noninvasive and continuous monitoring of the blood glucose level is an urgent requirement for diabetic patients to prevent complications of diabetes as well as the dangerous situation

#7595 - $15.00 USD Received 26 May 2005; revised 21 August 2005; accepted 22 August 2005

induced by a low blood glucose level. Presently, the monitoring of blood glucose level is being carried out by electrochemical or enzymatic methods with blood sampling by finger pricking many times a day. This conventional method provides neither noninvasiveness nor continuous monitoring. Various optical methods have been investigated to develop noninvasive and continuous monitoring of blood glucose level using near-infrared (NIR) spectroscopy[1-3], mid-infrared spectroscopy[4], Raman spectroscopy[5], polarimetry[6-7] and fluorescence[8]. But none of the methods has succeeded in measuring the blood glucose level with the accuracy required for clinical use.

Phenomenologically, the detected spectra are affected by various factors such as glucose concentration, water content, protein concentration, temperature, scattering characteristics, etc in skin tissues. Among these factors ,the temperature as a external condition impacts greatly to the noninvasive measurement of blood glucose. However there is little existing literature on temperature effects on tissue optical properties in the temperature field.

A positive temperature coefficient was found in a study by Troy *et al*[9] (1996) on canine prostate tissue, but the decrease in scattering coefficient seen experimentally with increasing temperature is therefore consistent with an increase in fluidity known to occur in lipids with increasing temperature.

It has been found by a Monte Carlo simulation of light propagation for the wavelength range from 1200 nm to 1800 nm that only 1□ change in the temperature induces about 500 mg dl^{-1} errors in the prediction of the glucose concentration[10].

Usually, we employ the multivariate analysis to determine the blood glucose, of which one model is a must. However, if the temperature of building the model is not same to the measuring temperature, the error caused by the temperature will be not ignored. So, the purposes of this study are to investigate the quantitative effect of temperature to the absorbance of aqueous glucose. Then we can decrease or eliminate the error induced by the temperature.

2. Method

The whole measuring process and set-up are shown as Fig. 1. Near Infrared (NIR) source can be obtained with broadband light source inducing the Acousto-Optic Tunable Filter (AOTF), which is made of T_eO_2 crystal. The driver of AOTF is provided by BRIMROSE Company of America.

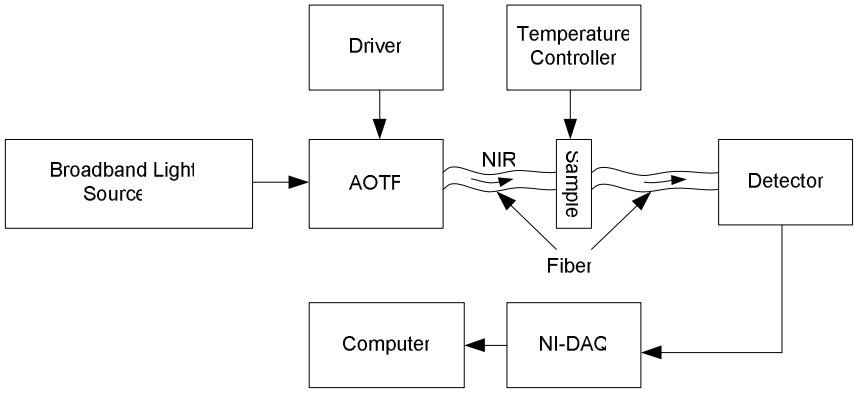

Fig. 1. Experimental set-up.

We will detect the transmission spectroscopy of aqueous glucose in the sample cell, which temperature can be controlled by semiconductor temperature controller, made by HAMAMATSU Company, and the control precision is up to ±0.1℃. The temperature during

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the measurement varies from 30℃ to 40℃, at a 2℃ interval, and aqueous glucose concentration ranges from 100mg/dL to 500mg/dL, at a interval of 100mg/dL, that is, we measure five different samples at five different temperatures. The optical length of every measurement is 1 mm and the transmission NIR light will be collected by the InGaAs detector, made by HAMAMATSU Company, then the data will be transferred into computer with DAQ software to calculate the absorbance.

3. Result

We first scan the transmitted energy in the whole wavelength range without sample as the background signal, noted as $I_0(\lambda)$,then measure the energy of 100mg/dL aqueous glucose at the temperature of 30℃, 32℃, 34℃, 36℃, 38℃, 40℃ respectively. So a group of spectra can be recorded at different temperature. In the same way, we can get other four groups of spectra with different temperature when the concentration of aqueous glucose varies from 200mg/dL to 500mg/dL. Fig. 2 shows that the absorbance of 100mg/dL aqueous glucose at the whole wavelength range changes with the temperature, from the insert chart in which we can see that the higher the temperature, the smaller the absorbance, which means the stronger the energy passing through. That is, absorption of aqueous glucose decreases with the increasing of temperature, also the absorbance decreases.

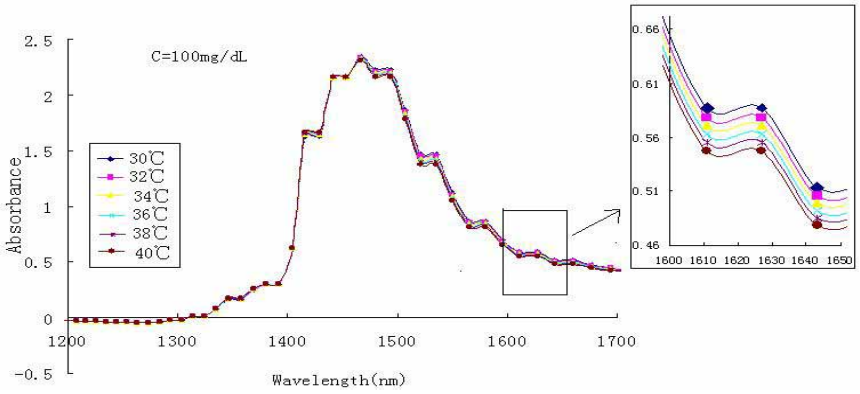

Fig. 2. Absorbance change with temperature (the insert larger figure shows the absorbance ranging from 1600nm to 1650 nm)

Figure 3 shows the absorbance change with temperature at different concentration at certain wavelength, the 1550nm is selected. From Fig. 3, it can be seen that the change of absorbance with the temperature is linearly decreased, and the same result can be found at other wavelength.

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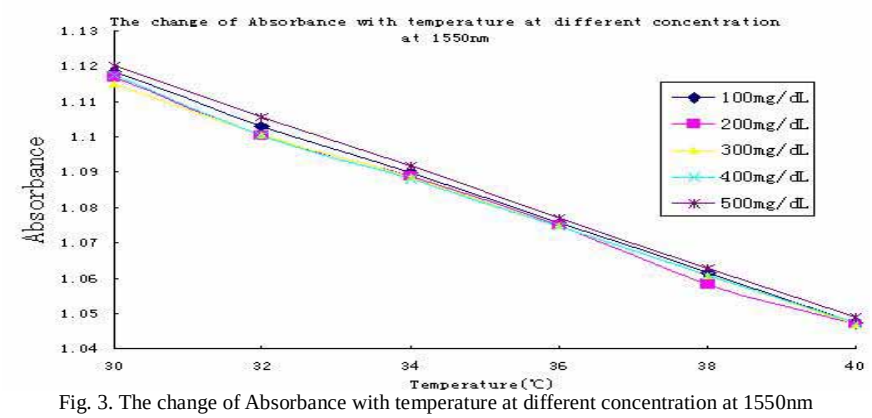

Fig. 3. The change of Absorbance with temperature at different concentration at 1550nm

From Lambert-Beer law:

$$I_T(\lambda) = I_0(\lambda) * e^{-\sum \varepsilon c l} = I_0(\lambda) * e^{-\sum A} \quad (1)$$

where $I_T(\lambda)$, $I_0(\lambda), A$ are transmitted light energy, background light energy and absorbance of sample respectively. Because there is only one component in aqueous glucose, so the formula above can be written as:

$$I_T(\lambda) = I_0(\lambda) * e^{-\varepsilon c l} = I_0(\lambda) * e^{-A} \quad (2)$$

then the absorbance of sample can be calculated as follow:

$$A(\lambda) = -\ln(\frac{I_T(\lambda)}{I_0(\lambda)}) \quad (3)$$

Based on the formula, at every wavelength point in the range from 1200nm to 1700nm and at different temperature, the absorbance of aqueous glucose can be deduced. Then the quantitative change of absorbance caused by the temperature can be computed at all wavelengths, shown as follow:

$$\Delta A / ^\circ C = (A_2 - A_1)/(T_2 - T_1) \quad (4)$$

Upon that, in the entire wavelength range from 1200nm to 1700nm, a temperature effect calibration curve of noninvasive measurement by NIR can be drawn as shown in Fig. 4. It can be seen from the tendency line, that only 1℃ change in the temperature induces about -7×10^{-3} and -4×10^{-3} errors in the absorbance of the aqueous glucose at the wavelength of 1550nm, 1610nm respectively.

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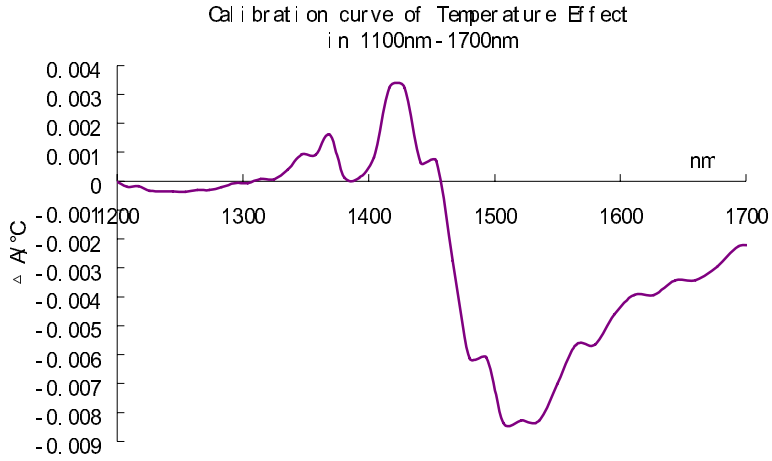

Fig. 4. Quantitative change of absorbance with temperature in the whole wavelength range

So when we do the noninvasive measurement of blood glucose, we should correct the examined result with the data read from the calibration curve if the temperatures of modeling and measuring are not uniform, but before that, we must test the temperature difference between modeling and measuring. Using this method, the error caused by the temperature change can be reduced even eliminated.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No.30170261), and the Natural Science Foundation of Tianjin (No. 023800411).

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