Noninvasive and Painless Urine Glucose Detection by Using Computer-based Polarimeter

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Abstract. Diabetes kills millions of people worldwide each year. It challenges us as researchers to give contribution in early diagnosis to ensure a healthy life. As a matter of fact, common glucose testing devices that have been widely used so far are, at least, glucose meter and urine glucose test strip. The glucose meter ordinarily requires blood taken from patient's finger. The glucose test strip uses patient's urine but records unspecific urine glucose level, since the strip only provides the glucose level in some particular ranges. Instead of detecting the glucose level in blood and using the non-specific technique, a noninvasive and painless technique that can detect glucose level accurately will provide a more feasible approach for diabetes diagnosis. The noninvasive and painless urine glucose level monitoring by means of computer-based polarimeter is presented in this paper. The instrument consisted of a power source, a sample box, a light sensor, a polarizer, an analyzer, an analog to digital converter (ADC), and a computer. The concentration of urine glucose concentration was evaluated from the curve of the change in detected optical rotation angle and output potential by the computer-based polarimeter. Statistical analyses by means of Gaussian fitting and linear regression were applied to investigate the rotation angle and urine glucose concentration, respectively. From our experiment, the urine glucose level, measured by glucose test strips, of the normal patient was 100 mg/dl, and the diabetic patient was 500 mg/dl. Our polarimeter even read more precise values for the urine glucose concentrations of those normal and diabetic of the same patients, i.e. 50.61 mg/dl and 502.41 mg/dl, respectively. In other words, the results showed that our polarimeter was able to quantitatively measure the urine glucose level more accurate than urine glucose test strips. Hence, this computer-based polarimeter could be used as an alternative for early detection of urine glucose with noninvasive and painless characteristics.

Keywords: glucose level, noninvasive and painless measurement, computer-based polarimeter.

1. Introduction

During the past years, one of the most critical issues on human health is diabetes mellitus [1]. Diabetes is a systemic disorder disturbing the body metabolism and may cause death [2]. In 2015, statistically speaking, more than 400 million grownup men and women were infected by diabetes mellitus, and it is predicted to rise by over 50% in the next 25 years [3]. Still, according to WHO, world health organization, it was reported that diabetes mellitus caused at least 1.5 million deaths in 2012. If the early detection of diabetes mellitus can be easily done, the risky effects of it can be significantly reduced. Since glucose levels are repeatedly used as an indicator of diabetes mellitus [3], then only can good instruments accurately detect the diabetes mellitus in terms of the glucose levels.
Furthermore, many researchers have developed instruments for measuring glucose levels. For instances, high-speed dual-wavelength optical polarimetries, near-infrared spectroscopies ([4-6]), multisensor noninvasive blood glucose monitoring systems [7], and blood glucose monitoring in the terahertz frequency range techniques [8]. However, those instruments are excessively complex and reasonably highly cost consuming. Thus, it is necessary to develop a simpler instrument for early detection of diabetes mellitus by measuring the glucose level. The measurement should be noninvasive and painless. Therefore, instead of measuring the glucose levels from blood, urine is more preferable. In this present study, we introduce a noninvasive and painless urine glucose levels computer-based polarimeter for diabetes early mellitus detection.

2. Experimental Method
A laser diode, a light dependent resistor (LDR), a polarizer, an analog to digital converter (ADC), and a computer were prepared to construct the computer-based polarimeter. The laser diode was chosen as a light source due to its coherence radiation characteristic. The laser diode was emitted to the solutions and then detected by the LDR. The LDR is able to transform light intensities to be output voltages. The voltages as analog data were then converted into digital data by means of ADC and connected to the computer, so that the data can be recorded and analyzed as well. In principle, the optical activity property of the glucose solution rotates the polarization direction of the polarized light when passing through the glucose solution. The amount of rotation is defined as a rotation angle. The rotation angle depends on (1) the nature of the solution, (2) the concentration of the solution, (3) the length of solution that is exceeded by light, (5) the wavelength of source light, and (6) the temperature of the solution. The angle of rotation ($\alpha$) can be mathematically expressed as

$$\alpha = \alpha_i \frac{L C}{100}$$  \hspace{1cm} (1)

Where $L$ is the length of solution that is exceeded by light and $C$ is the concentration of the solution. From the developed polarimeter, the data that can be read by the computer is the real time tabulation consisting of angel rotation polarimeter (in degree) and intensity light (in voltage). From those data, further analysis was done by executing Gaussian fitting to extract an angle that refers to the minimum value of output potential [9]. The concentrations glucose solutions were then calculated by Equation 1. The sensitivity of the instrument was evaluated by using linear regression analysis. To calibration correlate glucose solutions concentration and rotation angle is depicted in Table 1. while the instrumental set-up of the computer-based polarimeter is given in Figure 1.

| Cons. (mg/dL) | Rotation Angle ($^\circ$) | Change of rotation angle ($^\circ$) |
|--------------|---------------------------|----------------------------------|
|              | 1                         | 2                               | $\alpha_{\text{average}}$ ($^\circ$) |
| 0            | 86.990                    | 86.830                          | 86.990                             | 0                          |
| 25           | 87.120                    | 86.890                          | 87.005                             | 0.015                      |
| 150          | 87.160                    | 87.020                          | 87.090                             | 0.100                      |
| 500          | 87.090                    | 87.150                          | 87.120                             | 0.130                      |
| 5000         | 87.670                    | 87.350                          | 87.510                             | 0.520                      |

Table 1. Glucose solution concentrations and rotation angle
3. Results and Discussion

The collected data by means of the computer-based polarimeter is depicted in Figure 2. The lowest intensity represents that the polarizer and the analyzer are perpendiculars, so that the output potential is very low. This most moderate output potential is corresponding to the rotation angle of the measured solution. Figure 2 shows the relationship between rotation angle and output potential. As we can see from Figure 2, the graph can be approached by means of Gaussian fitting. The minimum value of the output potential is related to the rotation angle of 87.64°. Every measurement of the glucose solution concentration was repeated three times to obtain more precise and accurate measurement.

The sensitivity of the computer-based polarimeter can be evaluated by linear regression analysis as given in Figure 3. The linear fitting equation for Figure 3 is \( Y = 10040X - 401.19 \), where \( Y \) is the concentration of glucose solutions and \( X \) is the change of rotation angle \( \Delta \alpha (°) \) and correlation coefficient of \( R^2 = 0.96 \). with errors of \( S_B = 0.34 \) and \( S_A = 0.10 \). The value of the correlation coefficient of 0.96 indicates that (1) the experimental data is well fitted with the linear model and (2) the developed polarimeter is reliable for determining the concentration of glucose solutions.
The experiment to a human with sample one of the diabet and normal patient. The change of rotation angle for urine of patient was found from polarimeter measurement as 0.045° and 0.09°. Our polarimeter could even read more precise values for the urine glucose concentrations of those normal and diabetic patients, i.e. 50.61 and 502.41 mg/dl, respectively, depicted in Table 2. The urine glucose level, measured by glucose test strip, of the normal patient was 100 mg/dl and the diabetic patient was 500 mg/dL.

**Table 2.** The urine glucose level measurement by computer-based polarimeter

| Gender (M/F) | Age (Years) | Rotation angle α (°) | Chang of rotation angle Δ α (°) |
|--------------|-------------|----------------------|---------------------------------|
| Male         | 22          | 87.040 87.030 87.035 | 0.045                           |
| Female       | 61          | 86.890 87.270 87.080 | 0.090                           |

4. **Conclusion**

A very simple computer-based polarimeter has been successfully built-up. The instrument can be used for urine glucose levels for early detection of diabetes mellitus. Our experiment showed that the polarimeter might read more precisely being compared with urine glucose test strip. Therefore, this polarimeter can be applied for noninvasive and painless urine glucose levels measurement.

5. **References**

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