Simple and Low Cost Polarimeter System

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Abstract

Fundamental wave properties of light are wavelength, frequency, propagation direction, and polarization. In order to understand the polarization behavior of light as well as the polarization change during light matter interaction, we propose a simple multi point measurement system based on phase change. The total cost of experimental setup was less than 150$. Here in this paper, we utilized this system in order to measure the optical activities of glucose. We test the implemented polarimeter and results are verified with a commercial polarimeter. Possible applications of the system are discussed. This system offers data acquisition and signal processing with computer at basic level, which are substantial for multidisciplinary studies. Presented system could be used in undergraduate level physics and chemistry laboratories to teach the students the polarization dynamics in a simplified and practical way. We believe that phase dependent measurement setup will help inspire students to develop polarization based optics projects.

Keywords: Polarization, polarimeter, glucose.

Introduction

Measuring and understanding the state of polarization is crucial to science where some advanced physical tools and applications are dependent on the measurement of light polarization change; for instance, polarimetry (Lisboa and Sotomayo, 2010), ellipsometry (Trotter and Moddel, 1999), magneto and electro optical effect measurements (Teng and Man, 1990; Sato 1981) even in some of the practical applications in life such as in sun glasses, 3D movies, and polarization filters at photography. Moreover, polarization measurement systems have drawn great attention to teach the students the polarization dynamics in a simplified and practical way at undergraduate laboratory experiments (Lisboa and Sotomayo, 2010; Kraftmakher, 2009).

Measurement of polarization in terms of sensitivity is possible to perform with both simple and complex systems. Well-known simple one point measurement method is the cross polarization method, which needs rotating one of the polarizers to measure or to determine minimum light necessary for the arrangement of two polarizer perpendiculars. Having the intensity of light changing proportional to the $cos^2(\theta)$ where θ is the angle between the orientations of the first polarizer and the second polarizer (analyzer), is disadvantageous, which is to say that 0.1^o of change will cause 10^{-3} to 10^{-6} change in the intensity. Therefore, this method is applicable for high polarization changes. There exist more complicated systems that generally include modulation. Relatively expensive devices like Lock-in Amplifier or specific band pass filter designs are necessary so as to measure modulated signals (Sato 1981, Lin et. al., 2011).

In this study, we offer very simple and inexpensive multi point measurement setup with rotating analyzer. Components of the system can be easily found in any undergraduate laboratory. We applied this method to measure different sugar concentrations. We also discussed the possible applications and developments of this system.

Experimental Setup

In our proposed system, displayed in Fig. 1, have a laser pointer, a dc motor (can be replaced with other motors), two sheet polarizers, photodiode, and a data logger. Costs of the materials are below 150$ in total. The most expensive part of the system is the data logger, which can also be replaced with a microcontroller, or an analog to digital converter based computer interfaces.

We glued analyzer to the shaft of dc motor and placed a piece of black paper as a patch on analyzer to block the laser light at angular position (Fig. 1 part 2b). Size of patch was bigger than the laser beam. This patch was placed as a reference point.
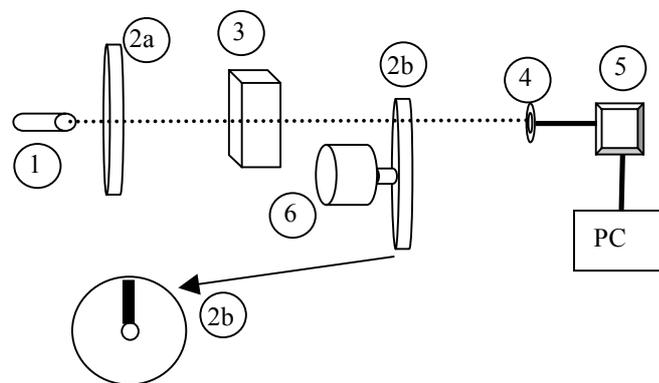

Figure 1. Parts of polarimeter system: 1. laser pointer, 2a. polarizer, 2b. analyzer, 3. sample tube, 4. photodiode, 5. data logger, 6. dc motor .

Photodiodes act as a current source under light. Very simple circuit, shown in Fig. 2, is used to convert the current to the voltage. Applied bias voltage (V_{cc}= 9 V) to the cathode of photodiode is necessary in order to fasten the response time. The voltage on R_L was measured and transmitted to the computer via Lab Jack U12 data logger. We used data logger at a sampling rate of 500 counts/s. DC motor is driven by using DC voltage source with variable resistant connected in series. Speed of DC motor was arranged by a changing variable resistant.
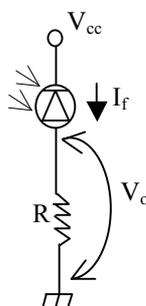

Figure 2. Photodiode circuit.

We used Jones calculus to calculate the effect of each optical component on the Electric field (E-Field) of the transmitted light. Since the laser pointer light is elliptically polarized, first polarizer (figure (1) part 2a) was used to obtain linearly polarized light of intensity I_0. For simplicity, polarized light after first polarizer was taken into account by assuming that it was polarized along the x-axis. Optically, active materials rotate polarization of E-Field by the angle of:

$$\alpha = V * d * g$$

(1)

Where V (^{o} ml/(mg.cm)), d (cm), and g (mg/ml) indicate the specific rotation, sample path length, and concentration; respectively. Coordinate axes rotation matrix is used to describe optically active sample.

$$S = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) \\ -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$$

(2)

We need to calculate the projection of the E-field components on the polarizer axis so as to describe the effect of ideal polarizer:

$$S = \begin{bmatrix} \cos(\vartheta) & -\sin(\vartheta) \\ \sin(\vartheta) & \cos(\vartheta) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \cos(\vartheta) & \sin(\vartheta) \\ -\sin(\vartheta) & \cos(\vartheta) \end{bmatrix}$$

(3)

where ϑ is the angle between x axis and polarizer axis. Third matrix on the left side of equation (3) can be described by coordinate axes rotation which makes x axis and polarization axis parallel. Second matrix eliminates perpendicular component of E-field to the polarizer axis. First matrix is used to rotate the coordinate axes back to the initial state. Since second polarizer rotating by w angular velocity, ϑ can be replaced by wt. Final form of analyzer matrix can be calculated by using equation (3):

$$S = \begin{bmatrix} \cos^2(wt) & \cos(wt)\sin(wt) \\ \cos(wt)\sin(wt) & \sin^2(wt) \end{bmatrix}$$

(4)

E-field vector after analyzer will be the result of the equation (5) where sample and analyzer Jones matrices are used.

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = A \cdot S \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} \cos(wt)\cos(\alpha + wt) \\ \sin(wt)\cos(\alpha + wt) \end{bmatrix}$$

(5)

The effect of patch on second polarizer is described by using F function and angular position interval, β:

$$F(wt) = \begin{cases} 0 & for \quad wt = \beta \\ 1 & for \quad wt \neq \beta \end{cases}$$

(6)

Transmitted light intensity, *I*, at the photodiode can be calculated by the relation of $I \propto EE'$, and using the equations (5) and (6), where E' is the complex conjugate of E-field:

$$I \propto I_0 \cos^2(\alpha + wt)F(wt)$$

(7)

Maximum change of the signal is at 45° for $cos^2(\theta)$ function; therefore, the position of patch has been arranged around that position. While black paper patch (*F(wt)*) which blocks the light at certain angular position, $cos^2(\theta)$ part of signal will shift by α degree with the effect of optically active sample; which is the main idea behind this design. As system components are not ideal, there will be absorption in the sample, noise in the detection, angular velocity change of motor during measurements, and DC component due to the other light sources and non ideal polarizer. Checking the angular velocity change and the noise elimination are very crucial issues for the current setup.

Results and Discussions

Before starting the optical activity measurements, first measurements were performed by the designed system without sample. Measured signal had high noise component. This component was eliminated by using smoothing. Fitted data was obtained by using LOWESS (Locally Weighted Scatter Plot Smoothing) method. This method was implemented in Matlab programming language with 'smooth' command. Smoothed signal and original signal were presented at Fig. 3. As displayed in Fig. 3, the obtained signal was fitted to the *a+bcos²(θ+c)* function. *a*, *b*, and *c* are DC component, amplitude, and phase difference between measured and calculated signals; respectively. Obtained results are in agreement with the equation (7).
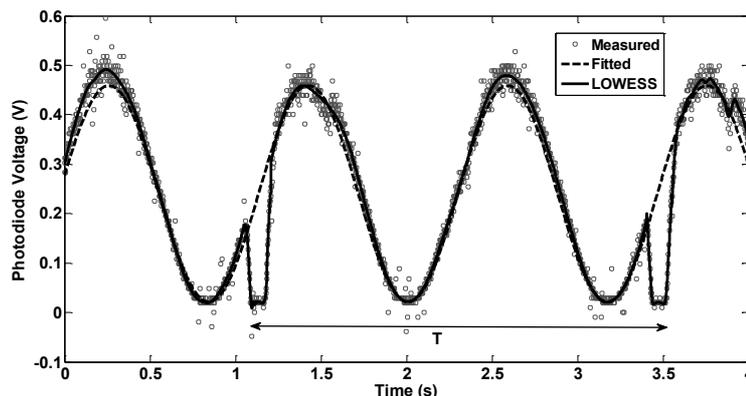
Fig. 3. Photodiode voltage ('o'), fitted data with LOWESS method (dash line) and fitted data to $a+b\cos^2(\theta+c)$ (solid line)

Furthermore, the designed system was utilized with different concentrations of glucose (dextrose monohydrate). Specific rotation of glucose was measured with commercial polarimeter as 2.1 dl/(gr.dm) or 0.021^o ml/(mg.cm). 3 ml of solution with different glucose concentrations were placed in the sample tube with 2 cm in width along the beam direction. The results for empty tube (without sample) and filled with 100 mg/ml measurements were shown in figure 4, and the attained periods of signals were 2.387 s and 2.408 s, respectively. Time component of signal was converted to degree unit in such a way to have periods by 360°. This way, period change of motor between measurements became insignificant. Phase difference between two measured data (α= T2-T1) were attained (α polarization rotation due to the optical activity of glucose). Measured and calculated polarization rotations are listed on table 1.

Glucose (mg/ml)	Calculated Optical Rotation	Measured Optical
33.33	$1,4^o$	1.2^o
66.66	$2,8^o$	2.9^o
100	$4,2^o$	4.4^o

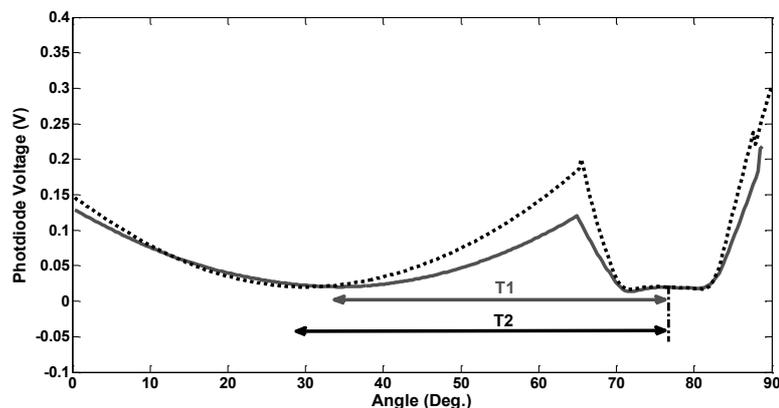*Table 1: List of calculated and measured optical rotation of samples*

Figure 4. θ vs. photodiode voltage. Empty (dotted) and with solution 100 mg/ml (solid)

Although current system is not suitable for sensitive measurements due to the motor instability, noise, and low sampling rate, it can be developed and used for any kind of polarization dependent measurements. For instance, it can be utilized to continuous detection of angular motion. It might also be possible to be use as an ellipsometer by changing reflection based setup. It is quite possible to increase sensitivity by using stable motor that also needs stable power supply, low noise amplifier circuits, and data logger with higher sampling rate.

One of the main objectives of this experiment is for undergraduate students to understand the polarization of the electromagnetic wave by observing interaction of light with optically active material. High school and undergraduate students conducted this experiment and by using the knowledge they obtained, designed projects about glucose measurement for diabetics, ellipsometry and magneto-optics (Oneren and Ozturk, 2008). This experiment can be used in physics, optics or chemistry undergraduate laboratory or classroom demonstrations to explain subjects related to Malus's Law, polarization optics, optically activity and polarimetry. We are of the opinion that phase dependent measurement setup will be a good challenge for students to understand polarization dynamics. As a result, very simple polarization measurement system can be constructed easily presented in this paper.

Acknowledgment

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