Effects of Light on the Intraocular Pressure of Aqueous Humor

Md. Taslim Reza1, Rinku Basak2, Prof. Dr. Md. Ashraful Hoque3
1Department of Electrical and Electronic Engineering, American International University-Bangladesh
2Department of Electrical and Electronic Engineering, American International University-Bangladesh
3Department of Electrical and Electronic Engineering, Islamic University of Technology, Bangladesh
Email: taslimreza@gmail.com

Abstract
High Intraocular Pressure (IOP) for longer period of time may guide the eye to different deceases and Glaucoma is one of them. Continuous, non-invasive and comfortable way of measuring IOP is necessary to detect the high IOP at the very early stage. Few methods are involved widely to measure the IOP in the doctor's chamber. Some other methods can be used by the person himself but those are still in research stage. In this paper, we utilize the basic characteristics of white light and also the physical characteristics of aqueous humor and cornea to propose a continuous, non-invasive way to measure IOP. The change of intraocular pressure is relates to the change of refractive index and that changes are shown with proper plotting.

Keywords: *Light effects, Intraocular Pressure, IOP.*

1.Introduction

Eye problem is a great challenge for aged population. The problem increases dramatically with the aging of population. Proper detection and timely diagnosis is the best answer for this challenge [1]. The average normal IOP is about 15 mmHg but it can vary between 12 and 20 mmHg in a normal eye. There are great individual variations and a pressure higher than 21 mmHg does not necessarily damage the eye. On the other hand sometimes an eye with an IOP within the normal range does not work properly and thus needs to be treated [2]. Different kinds of problems with the eyes become more common. Glaucoma is one of the most common causes for visual disability throughout the world [1]. Most of the glaucoma patients are over 65 years old. The human age correlates strongly with the visual disabilities. The number of glaucoma patients increases with the aging of the population in the near future. In the detection and the treatment of the glaucoma the measurement of the intraocular pressure (IOP) has been found to be important. Glaucoma patients often have higher intraocular pressure readings than healthy persons. The variation of the intraocular pressure is also significantly higher among the glaucoma patients than healthy persons. The measurement of intraocular pressure has been done for a long time in the doctor's office with an applanation tonometer. This leads to measure the pressure within the eye at that very moment and at that very position of the patient. If measurements are done more frequently the patient has to go to the doctor every time; on the other hand, possible changes may be undetected due to long duration between two measurements. For this, some development has been done in order to find a new technology for measuring the intraocular pressure in a non-clinical manner. Unfortunately even these new solutions have not solved the problem of continuous measurement of even a reliable self-measurement system yet [3]. The measurement of the IOP in a non-clinical manner is definitely an important goal for the near future. Even though many attempts have been made in order to solve this problem none has proved to be functional in the real life so far [4, 5]. There are a lot of patents concerning this topic from the past few years and many ideas have been thrown out in the air. Even still it seems that only few radical and original attempts to approach the problem has been made and even fewer seem to have good possibilities to be the answer to the need for a continuous measurement of the IOP [6, 7, 8, 9]. Most of the suggested methods are just an improvement of an existing system or a portable version of an old method [10, 11, 12, 13].

In this work, a measurement system is proposed for measuring intraocular pressure on the basis of light effects on aqueous humor. Effects of light on the intraocular pressure have been studied with the aim of developing a non-clinical measurement system.

2.PROPOSED MEASUREMENT SYSTEM

In this proposed measurement system the characteristics of white light, propagating from dense medium to light medium, is used. The basic phenomenon of aqueous humor is to change its density with respect to the intraocular pressure (IOP) of eye also used in this proposed measurement system. One visible contact lens having white light source and light intensity sensor could lay on the cornea surface of the eye. Obviously the white light source and light intensity sensor will be beyond the visible area of the eye sight. Fig. 1 shows the total hardware arrangement of the proposed measurement system. From the basic physical structure of the eye, cornea is denser than that of aqueous humor [14]. On the other hand, white light contains different components having different wavelengths as shown in table 1. So, when the white light propagating from cornea to aqueous humor, the refractive angle will differ from one light component to another. According to the wavelength violet light component will gives the minimum refractive angle and red light component produce highest refractive angle. The position of the white light source and the light intensity sensor will be in such a way that in the normal intraocular pressure (between 12 and 20 mmHg) all light component produce the refractive angle more than 90^o. So, the entire light component will fully reflect back to the light sensor. When the intraocular pressure rises to more than 20 mmHg, the density of aqueous humor will increase a bit and that is why first the violet component of white light will failed to fully reflected back and it goes through the aqueous humor. Based on the rise of the IOP, aqueous humor density will increase more and more. Due to this change of density of aqueous humor, after the violet component, the blue light component and then the green light component will fail to fully reflect back to the light intensity sensor and so on. Now by measuring the light intensity using the light intensity senor, the change of intraocular pressure could understand.

3.SIMULATIONS AND RESULTS

The refractive index is represented by the following equation [15]

$$\frac{n^2-1}{n^2+2}(1/\bar{\rho}) = a_0 + a_1\bar{\rho} + a_2\bar{T} + a_3\bar{\lambda}^2\bar{T} + a_4/\bar{\lambda}^2 + \frac{a_5}{\bar{\lambda}^2-\bar{\lambda}_{UV}^2} + \frac{a_6}{\bar{\lambda}^2-\bar{\lambda}_{IR}^2} + a_7\bar{\rho}^2$$

(1)

where, n is the refractive index of aqueous humor.

Density, $\bar{\rho} = \rho/\rho^*$, where, ρ is the density of aqueous humor and ρ^* is the reference density of 1000 kg/m^3.

Temperature, $\bar{T} = T/T^*$, where, T is the absolute temperature and T^* is the reference temperature of 273.15 K

Wavelength, $\bar{\lambda} = \lambda/\lambda^*$ where, λ is the light wavelength and λ^* is the reference wavelength of 0.589 μm.

The density of aqueous humor ρ is written as [16]

$$\rho = \rho_0 / \left(1-(p-p_0)/E\right) \qquad (2)$$

where, E is the bulk modulus fluid elasticity in N/m^2, ρ is the final density in kg/m^3, ρ_0 is the initial density in kg/m^3, p is the final pressure in N/m^{2}and p_0 is the initial pressure in N/m^2.

The analytical expressions of refractive index and density of aqueous humor have been simulated using MATLAB. After simulation by putting numerical values of all the needed parameters the above equations are computed and the results are presented in Fig. 2. According the equation (2) desired range of the aqueous humor pressure is converted to density. In this work, the characteristic of aqueous humor is taken as water [17]. The range of the density of aqueous humor is taken as 1600 kg/m^3 - 3000 kg/m^3.

The change of the refractive index is calculated by using equation (1), where there are three variable factors; i) Density, ii) Temperature and iii) Wavelength. Here, temperature and wavelength are kept constant and the change of the refractive index is found by only varying the density of aqueous humor. For six different colors light (Red, Orange, Yellow, Green, Blue and Violet) the change of the refractive index is calculated by varying the density and the obtained results are plotted as shown in Fig. 2. Obviously one color is a combination of a range of wavelength, but in this work only one particular wavelength is taken in the calculations to represent that particular light. Here, the bulk modulus fluid elasticity, E is taken as 2.15 10^9 (N/m^2).

From fig. 2 it is observed that the refractive index varies linearly with the variation of density of aqueous humor. It is found that the density varies with the variation of pressure in the aqueous humor which further varies the refractive index. The change of the refractive index is different for different colors. A maximum variation is observed for the violet color, whereas a minimum variation is observed for the red color.

From the fundamental principle of light critical angle can be represented using Snell's equation

$$\theta_c = \arcsin\left(\tfrac{n_2}{n_1}\right) \qquad (3)$$

where, θ_c is the critical angle, n_2 is the refractive index of light medium and n_1 is the refractive index of dense medium.

Aqueous humor works as the light medium with respect to cornea and its normal refractive index is 1.333 as water. But this refractive index is changed by the difference of the IOP. Cornea is the dense medium and its refractive index is taken as 1.37 [2]. It is assumed that the refractive index of the cornea remain constant for the predicted pressure change of aqueous humor. For different refractive index of aqueous humor due to the change of IOP of eye, the critical angle of a particular light is being changed. This change is simulated by the equation (3) and the obtained results are plotted as shown in Fig. 3. Here, six different colors are considered in the calculations.
A linear variation of critical angle for different colors has been observed with the variation of refractive index of aqueous humor as shown in fig. 3. For different colors the changes of the critical angles are different and the variations are presented in Table 2. It is found that the variation for the violet color is the maximum; on the other hand, the variation for the red color is the minimum.

4.CONCLUSIONS

Modern light sensing technology is very much capable to trace very small deflection of light. More practical research data will give more confident to implement our proposed our method practically. In this paper we neglect different parameters, such as the change of the position of the incoming light and position of the sensing electronics due to the IOP fluctuation. Those parameters would affect the measurement system. For detail calculation those parameters should take into account. This proposed system could give a very easy, non-invasive and comfortable IOP measurement system as a hole.

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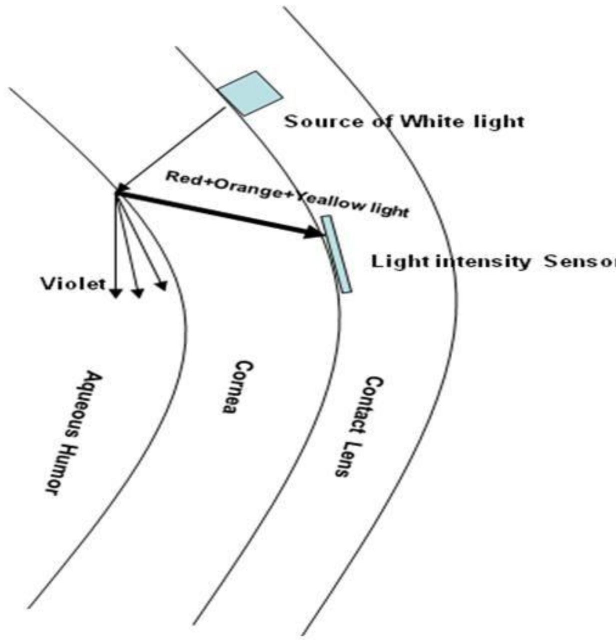


Fig. 1 Proposed eye pressure measurement system.

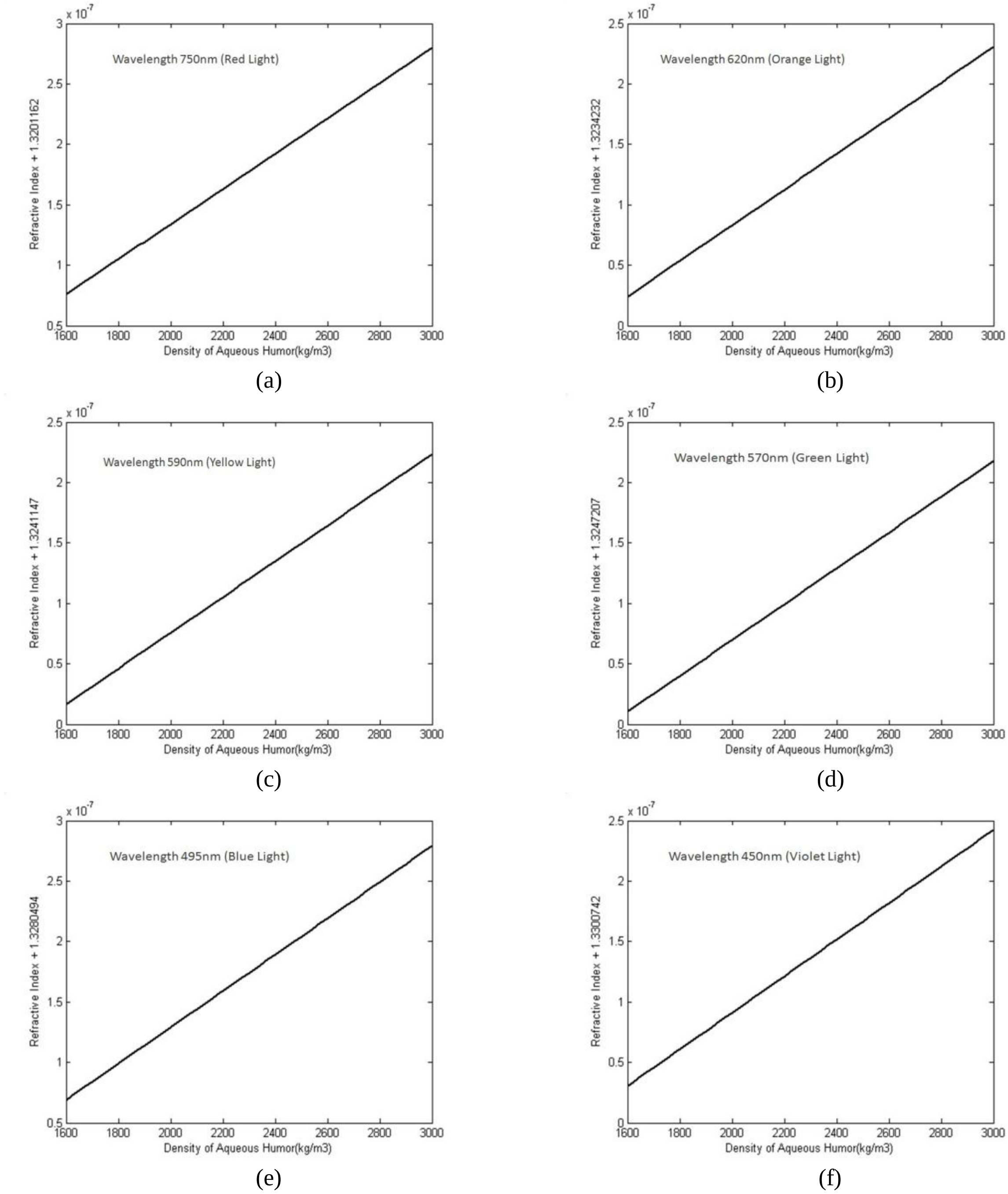
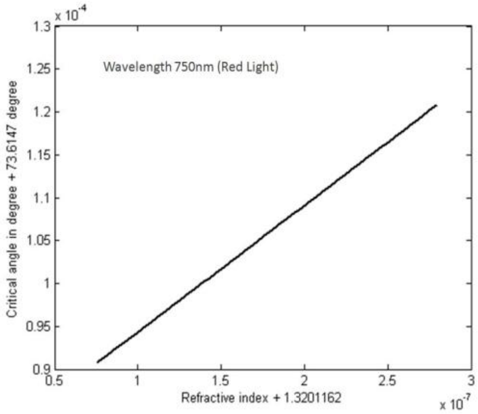
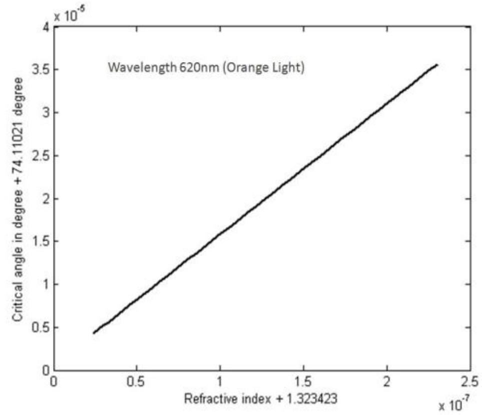


Fig. 2 Plot of refractive index vs. density of aqueous humor for (a) red light, (b) orange light, (c) yellow light, (d) green light, (e) blue light and (f) violet light.



(a)



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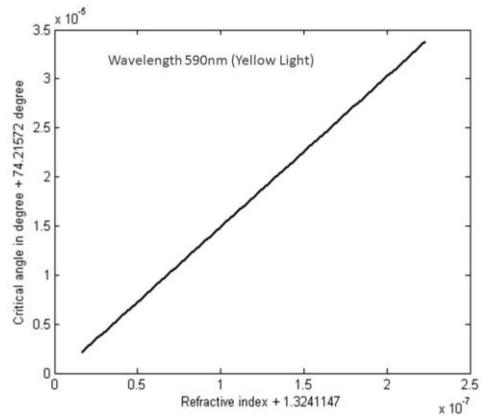

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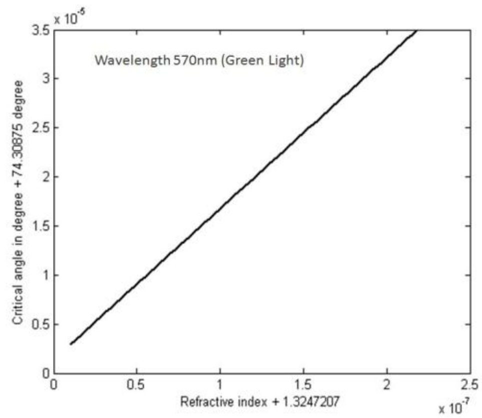

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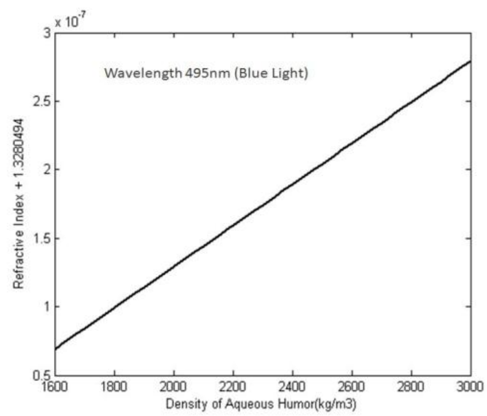

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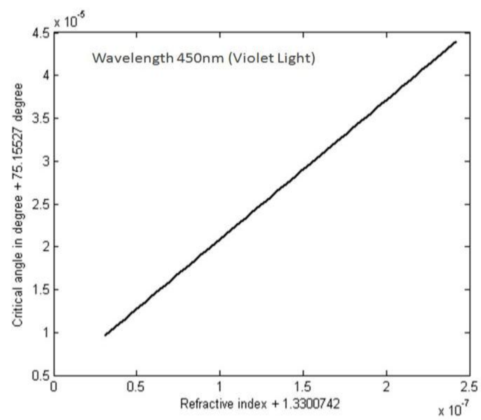

(f)

Fig. 3 Plot of critical angle vs. refractive index of aqueous humor for (a) red light, (b) orange light, (c) yellow light, (d) green light, (e) blue light and (f) violet light.

Table 1: Different components in white light and there wavelength

Different lights	**Wavelengths**
Red	620 - 750 nm
Orange	590 - 620 nm
Yellow	570 - 590 nm
Green	495 - 570 nm
Blue	450 - 495 nm
Violet	380 - 450 nm

Table 2: Critical angle changes due to pressure

Color	**Critical angle for initial pressure of 1600 kg/m^3**	**Critical angle for final pressure of 3000 kg/m^3**	**Difference**
Red	73.61479^o	73.61482^o	0.00003^0
Orange	74.110215^o	74.110245^o	0.00003^0
Yellow	74.2157225^o	74.215755^o	0.0000325^0
Green	74.3087525^o	74.308785^o	0.0000325^0
Blue	74.8296925^o	74.829725^o	0.0000325^0
Violet	75.15528^o	75.155315^o	0.000035^0