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The Development of Spectroscopy System for Non-Invasive Measurement of Skin Blood Oxygen Saturation

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Abstract. This paper presents the use of the developed spectroscopic system for noncontact measurement of one’s skin blood oxygen saturation (S,O₂). This study employed light diffusion model in the prediction of the required value using light source of wavelength 488 nm, 522 nm and 684 nm. The performance of this system was tested on ten volunteers of different skin tone to investigate the robustness of the system. The mean and standard deviation of S,O₂ value calculated for the recruited subjects is given by 71 ± 4.7 %. The results revealed differences in the predicted value with the recruits’ skin tone. This work concluded that the developed system may potentially be used in clinical settings to determine skin oxygen saturation and to monitor wound healing progress.

1. Introduction

Hemoglobin is a protein in red blood cells that carries oxygen to one’s organs and tissues, and at the same time transports carbon dioxide gas from organs and tissues back into the lungs to be expelled from the system. The percentage of hemoglobin is commonly referred to as the blood oxygen saturation. Oxygen has a significant role in wound healing [1-2], this element is essential to help in providing the additional energy source needed for tissues repairing. Under conditions of systemic hypoxia, there would be a decrease in wound oxygen level, henceforth affect the healing outcomes. Healthy people would have a normal range of arterial blood oxygen saturation, S,aO₂, fluctuating from 95 to 100 %; a drop in this value to 90 % is sometimes common and does not raise an alarm.

Hemoglobin level test is a blood test that provides information on the effectiveness of red blood cells in carrying oxygen to cells [3]. This test is important because the amount of oxygen readily available to the tissues depends upon the concentration of hemoglobin in red blood cells and local perfusion of the tissues. In the events of hemoglobin insufficiency, tissues would be deprived of oxygen, both heart and lungs would have to work harder to compensate for the demand.

Some commercial and readily available instruments include pulse oximeter and fiber-optic pulmonary artery catheter oximeter [4]. Both of these equipments are commonly used for in-vivo blood oxygen saturation measurement. Pulse oximeter is a non-invasive technology that uses a contact probe for measurement of one’s S,aO₂ from well perfused fingertip. Nonetheless, the use of a probe is not practical if burnt or wound injuries were located on the extremities where the probe would be used. Besides, pulse oximeter failed in its prediction of the S,aO₂ value under medical situations such as hypovolemia, hyperthermia, hypoxia, hypoxemia and hypoperfusion as it cannot distinguish between
different forms of hemoglobin [5]. Meanwhile blood gas analyzer is another means to measure the oxygen saturation in blood. Even though this method is able to provide a more accurate estimation of blood oxygen saturation, it is an invasive approach. This work aims to develop and demonstrate the use of a non-invasive and non-contact spectroscopic system in the measurement of one’s blood oxygen saturation with the assumption that oxyhemoglobin (HbO₂) and deoxyhemoglobin (Hb) were the only absorbers present. It is also the objective of this study to propose the use of this invention for future clinical use.

2. Material and Method

2.1. Experimental system and subjects

The in-house developed optical system shown in figure 1 consisted of a Light-Emitting Diode (LED model no. SMD 5730), a reflective diffraction grating (model no. GR50-1205), a plano-convex lens and an imager (model no. CW835). The LED was aligned at an angle of 45° from normal to illuminate the surface of the selected skin site. Light interacted with the skin would be reflected onto the diffraction grating; light diffracted from this element produces a spectrum of visible light. A slit was placed in front of the diffraction grating to gate the light. Only light of the selected wavelength would pass through the slit. This single wavelength light passed through a lens before it was focused onto the imager. The latter was placed at a distance of approximately 150 mm from the skin site. The selection of the wavelength is via the rotation of the diffraction grating. This work chose light beam of wavelength 488 nm, 522 nm and 684 nm for illumination of the skin owing to the large variability in the hemoglobin absorption at these wavelengths. The search of these selected wavelengths is via the change in the diffraction angle of the diffraction grating from normal as followed:

\[ n\lambda = d(\sin i + \sin i') \]  

where \( n \) is the order of diffraction, \( \lambda \) is the diffracted wavelength, \( d \) is the grating constant (the distance between successive grooves), \( i \) is the angle of incidence measured from the normal and \( i' \) is the angle of diffraction measured from the normal. This study used the first order diffraction beam, \( n = 1 \) and \( d \) is calculated as 833 µm.

In this work, experiment was conducted on the palm of the right hand of ten healthy volunteers (aged between 23-27 years) of both genders with different skin tone to investigate the range in the predicted blood oxygen saturation, \( S\text{O}_2 \). These subjects gave their consent to participate in the study. For each subject, three data were consecutively collected from the same skin site.

![Non-contact optical spectroscopy system](image-url)
2.2 Analytical model and iterative fitting process
Each image collected from the imager was calculated for its overall mean value to speed up the processing time. An algorithm was written in MATLAB to calculate the light attenuation of each wavelength given by:

$$A = \log \left( \frac{I_w}{I_s} \right)$$

(2)

where $I_w$ is the light intensity reflected from the palm of the hand while $I_s$ is the light intensity reflected from the surface of a white reference sheet. The prediction of the required health parameter value is via the wavelength, $\lambda$, dependent light diffusion approximation model defined as followed [6]:

$$A(\lambda) = \frac{3\mu_a(\lambda)}{\mu'_s(\lambda)}$$

(3)

where the relationship between light absorption, $\mu_a$, and $S_O2$ is given by

$$\mu_a(\lambda) = \left( (\varepsilon_{HbO2} - \varepsilon_{Hb})S_t O_2 + \varepsilon_{Hb} \right)T.$$  

(4)

The wavelength dependent extinction coefficient value, $\varepsilon$, of the hemoglobin components can be found in the work by Zijlstra [7]. The symbol $T$ in equation (4) denotes total blood concentration and is taken as 268 $\mu$mol/L[8]. Meanwhile the reduced scattering coefficient, $\mu'_s$, shown in equation (3) is expressed as:

$$\mu'_s(\lambda) = 2 \times 10^4 \lambda^{-1.5}.$$  

(5)

The search of the required $S_O2$ value shown in equation (4) is via an iterative fitting algorithm using the `fminsearch` function in MATLAB. The optimal $S_O2$ value is assumed to have been found when the absolute difference between the experimentally measured value and the light attenuation calculated from equation (3) is less than $10^{-30}$.

3. Results
This study conducted experiments on ten volunteers; among these volunteers five were female (volunteer index number 1, 3, 6, 7 and 8 in figure 2) while others were male. The mean and standard deviation of the $S_O2$ value predicted for each recruited volunteer using three consecutively collected data are plotted in figure 2. The average of $S_O2$ value is calculated as $74 \pm 3.3 \%$ and $68 \pm 6.1 \%$, respectively, for the recruited females and males. Meanwhile the overall average of the $S_O2$ shown in figure 2 is calculated as $71 \pm 4 \%$. The difference in the $S_O2$ value predicted for the two genders was statistically evaluated using an unpaired two-tailed student $t$-test in SPSS software (SPSS 22, Inc., Chicago, Illinois) with confidence level of 95 \%. This statistical test revealed a significance value, $\rho$, of 0.752.

4. Discussion
Figure 2 showed that the skin blood oxygen saturation value predicted for majority of the recruited volunteers fluctuated in between $70 - 80 \%$, with the overall mean value is calculated as $71 \%$. This range of blood oxygen saturation was also observed in other related works [9, 10] for measurement on the palm of the hand where abundance of arteriovenous anastomoses (AVAs) can be found. The AVAs provides a direct shunting path between venules and arterioles. The measured data reflected from skin is, therefore, taken as the average of blood oxygen saturation information carrying signals from local
capillaries, veins and arteries. Meanwhile the calculated significance value, $\rho$, of 0.752 indicates a high similarity in the value predicted for both genders.

This work found a considerably low $S_O_2$ value predicted for volunteer index 5 with mean and standard deviation value calculated as $30 \pm 6\%$. This is owing to the fact that the corresponding volunteer has a comparatively darker skin tone compared to others. This showed that the employed analytical technique is sensitive to one’s skin pigmentation. This can be overcome by taking into consideration changes in light attenuation with skin melanin absorption via equation (4), as is demonstrated in the work of [11]. Nonetheless it must also be mentioned that differences in one’s skin thickness, health status, age and diet would also affect the predicted value [12].

The obtained results revealed the developed spectroscopy system and the employed analytical strategy may potentially be further improved in the estimation of one’s $S_O_2$. In addition, the use of light of wavelength 488 nm, 522 nm and 684 nm as the illumination beam is shown suitable for use in developing a skin blood oxygen saturation monitor. Among the possible clinical applications, following improvement of this system, include non-invasive evaluation of wound healing progress, and in post-operative care to monitor the success of skin graft.

5. Conclusion

This work demonstrates the use of a spectroscopy system to non-invasively monitor one’s skin blood oxygen saturation using light of wavelength 488 nm, 522 nm and 684 nm. The obtained results revealed an overall mean $S_O_2$ of $71 \pm 4\%$, while no significant difference was observed for the value predicted for the two genders. This work concluded that the performance of the analytical strategy may be improved by including the effects of skin pigmentation on the total light attenuation defined in the employed analytical model.

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References

[1] M H Chen, C W Kerechanin, D G Greenspan, T B Criss, S C Franckowiak, J A Vincent and R S Pattay 2005 Johns Hopkins Apl Technical Digest 26 67
[2] A Huong, S Philimon, and X Ngu 2017 *Journal of Innovative Optical Health Sciences* 10 1750041
[3] D Nicoll, C M Lu, M Pignone and S J McPhee 2008 *Pocket Guide to Diagnostic Tests* (The McGraw-Hill Companies)
[4] S Whitener, R Koneske, and J B Mark 2014 *Best Practice & Research Clinical Anaesthesiology* 28 323
[5] T Slusher, A Bjorklund, H T Aanyu, A Kiragu and Christo Philip 2017 *J Pediatr Intensive Care* 6 066
[6] A K C Huong 2012 *Spectroscopic analysis of scattering media via different quantification techniques* (The University of Nottingham)
[7] W G Zijlstra, A Buursma and O W van Assendelft 2000 *Visible and near infrared absorption spectra of human and animal hemoglobin: determination and application*; VSP
[8] A Huong and X. Ngu 2014 *Journal of Innovative Optical Health Sciences* 7 1
[9] S Philimon, A Huong and X Ngu 2017 *IOP Conference Series: Materials Science and Engineering*, 226 1
[10] S Philimon, A Huong and X. Ngu 2016 *APRN Journal of Engineering and Applied Sciences* 11 3951
[11] A Huong and X. Ngu 2016 *Proceedings of the 3rd International Conference on Biomedical and Bioinformatics Engineering* 46
[12] S De Spirt, H Sies, H Tronnier and U Heinrich 2012 *Skin Pharmacol. Physiol.* 25 2