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Optimizing the Distance between Organic Light Emitting Diode (OLED) and Organic Photodetector (OPD) for the Reflectance Pulse Meter Sensor

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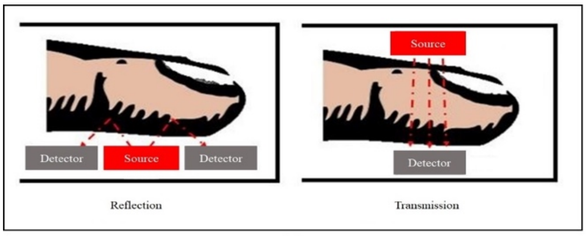
Abstract: *Pulse oximetry device has been used to observed the pulse rate and oxygen saturation in human blood at prior health examination before further diagnose can be performed. The reflection based pulse oximetry has been proposed by comparing reflection and transmission type. The comparisons were performed by using the Monte Carlo simulation method for human fingertip structure to find the optimum distance between light source and detector which shows closer distance has higher signals compared with others. Actual devices were also fabricated to observe the differences between closer and larger distance between the light source and detector. Higher signal-to-noise ratio (SNR) was observed for the closer distance at low power consumption which brings to the possibility of lower power consumption pulse meter device in the future.*

Keywords: PPG sensor; pulse meter; Monte Carlo simulation

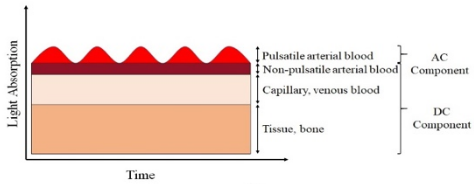
1. INTRODUCTION

Pulse oximeter is a device which using a noninvasive technique to monitor oxygen saturation in the blood and also the pulse rate as an initial procedure before further diagnosing procedure can be perform onto a patient [1]. The signal and data obtained from the pulse oximeter device will be used to appraised the numerous medical conditions that related to the behavior of the heart and lungs [2]. In principle, there are two types of pulse oximeter available in the market which are transmission and reflection type as shown in Fig. 1. During pulsatile condition, the volume of oxygenated blood (HbO_2) will changed repeatedly while the deoxygenated blood (Hb) and other components will remain the same. The variations of the light absorption at different wavelength for each of the components also will determine the oxygen saturation and pulse rate. HbO_2 component has higher absorption coefficient at red wavelength (600-660 nm) compared with the Hb component which has higher absorption at green wavelength (550-550 nm) [3].

Previous study by Akl et al [4] demonstrated an experiment to determine the optimal spacing between transmitting and receiving optical fibers in reflectance pulse oximetry. In subsequent study, Akl et al [5] focused on the optimal distance between the source and detector by using point source Monte Carlo simulation. In contrast, Huang et al [6] demonstrated a comparisons between simulation and actual device for a ring-type pulse oximeter with multi detector in order to increase the efficiency of the device. However, the comparisons between the reflective and transmission type at finger structure and also the comparisons between location of the pulse oximeter to be used are very important to determine the efficiency and effectiveness of the device.



(a)



(b)

Fig. 1. (a) Principle of pulse oximeter. (b) Light absorption components.

In this study, the simulation process to determine the optimal distance between light source and detector was performed for the fingertip structure. The comparisons between reflection and transmission was performed in order to observed the detection signal between these two types.

2. METHODOLOGY

2.1 Fingertip Structure Model

As for the fingertip structure used in this model, it consists of skin, bone, arteries and veins. Fig. 3 shows the structure and dimension of the fingertip structure.

2.2 Optical Properties

For the simulation process, several parameters need to be taken into consideration and all the parameters are shown in Table 1 [6].

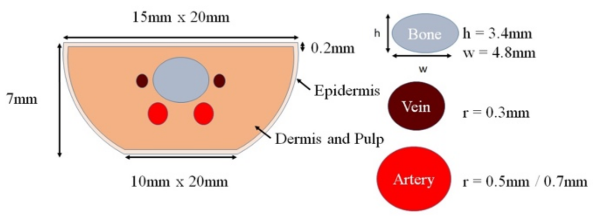


Fig. 3. Fingertip structure model.

2.3 Simulation Process

In order to determine the optimum distance between source and detector, multiple simulations were performed by changing the distance between them at the initial thickness of HbO_2 and after increasing the thickness to imitate the pulsatile condition. Fig. 4 and Fig. 5 show the location of source and detector for both structures and also at two different conditions which are transmission and reflection.

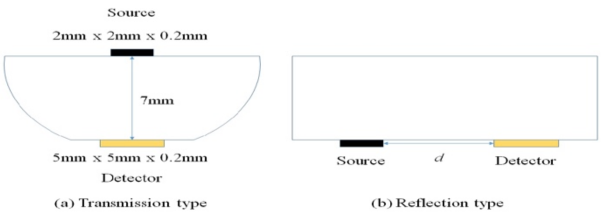


Fig. 5. Position of source and detector for fingertip structure for transmission and reflection type.

2.4 Monte Carlo Simulation Method

This method has been widely use to study the light scattering and distribution within the biological tissues due to its flexibility and freedom. For this simulation, Lighttools® software was used and it is based on the Henyey-Greenstein phase function where it describes the scattering behavior and given by [6]:

$$P_{HG}(\theta) = \frac{w(1-g^2)}{(1+g^2-2g\cos(\theta))^{\frac{3}{2}}}, \qquad (1)$$

Where P_{HG} is the intensity in a specific degree. w and θ represent the normalization parameter and the direction of scattering, respectively. The scattering angle from 0° to 180° where the power distributes is represented by this phase function. From here, the scattering anisotropy parameter (g) [6]:-

$$g = \langle \cos\theta \rangle = \int_0^{\pi} P_{HG}(\theta)\cos\theta\, 2\pi \sin\theta\, d\theta. \qquad (2)$$

2.5 Device Fabrication

The actual device was fabricated in order to verify the results obtained from the simulation. Fig. 6 shows the dimensions for the Organic Photodetector (OPD) and red light emission Organic Light Emitting Diode (OLED) used in this device system. The OLED was located at the center and circulated by the OPDs at both sides. The differences between these two devices are the distances between the OLED and OPD and also the size of the OLED as shown in Fig. 6.

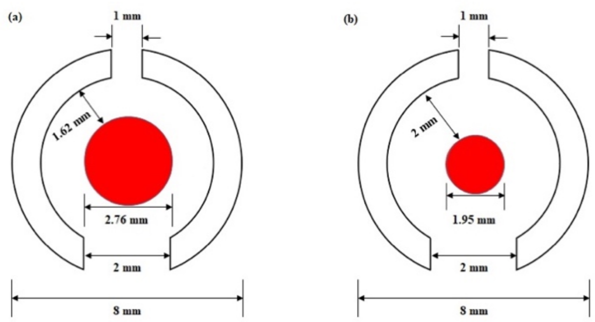


Fig. 6. The OLED and OPD dimension in (**A**) Device-1 and (**B**) Device-2 [7].

The OPD and OLED were fabricated using the vacuum process and the structure for both devices are illustrated in Fig. 7.

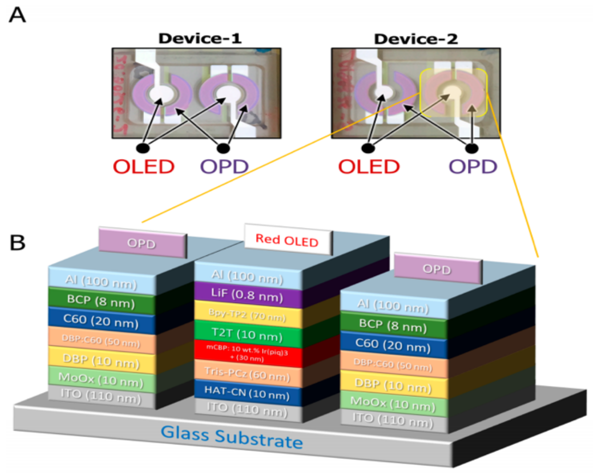


Fig. 7. The layer by layer structure for the OPD and OLED for this system [8].

Table 1. Optical properties for fingertip structure.

Material	Refractive Index (η)	Anisotropy parameter (g)	Absorption Coefficient (μ_a) in mm^{-1}	Scattering Coefficient (μ_s) in mm^{-1}	MFP in mm
Epidermis	1.433	0.79	0.27	10.7	0.093458
Dermis and pulp	1.380	0.91	0.05	8.6	0.115600
Bone	1.400	0.92	0.05	33.1	0.030100
HbO_2	1.363	0.98	0.20	77.5	0.012900
Hb	1.362	0.98	0.72	77.5	0.012800

3. RESULTS AND DISCUSSION

3.1 Simulation Results

In the simulation, the light source given was 656 nm at 1 mW and the number of photons was 10^8. As in Fig. 8, it shows the signal detected at the detector for reflection and transmission type for fingertip structure. At 0 mm distance, the signal obtained was $3.1\text{x}10^{-11}$ A/mm^2 which was higher than other distances and also with the transmission type where the signal was $6.8\text{x}10^{-13}$ A/mm^2. However, the signal from the transmission type was higher than the reflection type when the distance between the source and detector for the reflection type was at 4 mm and above. It shows that at some point, the transmission has higher detection signal compared with the reflection. Nevertheless, it still depends on the thickness of the fingertip since the thickness of fingertips are varies upon each person.

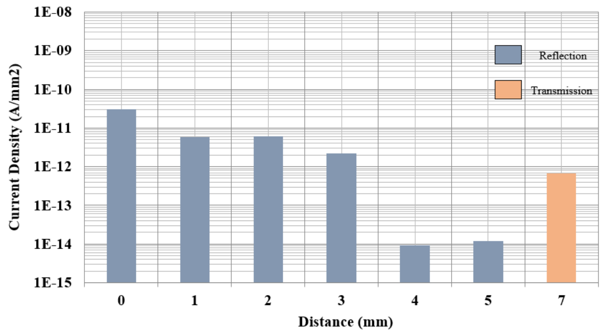


Fig. 8. Signal detected at the detector from the reflection and transmission mode at the fingertip structure.

The results showed that reflection type has higher detection compared with the transmission type. The reflection has more advantages from the transmission type since it can be attached to any part of the body.

3.2 Device Characteristics

The actual device has been fabricated in order to observe the comparisons between the simulation and actual data. As has been showed previously in Fig. 6 and Fig. 7, a round shape of red OLED at the center and the two OPDs surrounding the OLED so that the absorption of the signal can be optimize. Fig. 9 shows the characteristics and performances of both OPD and OLED devices. The optimum intensity of light was at 625 nm based on the emission spectra in Fig. 9(a). The maximum External Quantum Efficiency (EQE) for the OPD was about 37% at 625 nm for zero-bias condition which sufficiently overlapped with the peak of electroluminescence (EL) of the red OLED wavelength as shown in Fig. 9(b).

3.3 PPG Signal

The photoplethysmogram (PPG) was measured by using both fabricated devices. Based on Fig. 10, the signals obtained were stable and clear for both devices. In Fig. 10(a), the PPG amplitude was about 100 mV for the Device-1 and less than 45 mV for the Device-2 in Fig. 10(b) with a constant voltage of 5 V of the OLED for both devices.

Since both devices had different size of OLED and distances between OLED and OPDs, a unify power was used by supplying a constant current where the driving currents were varied at 2.4 µA and 93.6 µA for both devices. Devicec-1 has the OLED size of 5.99 mm^2 and distance between OLED and OPD at 1.62 mm. Whereas, Device-2 has the OLED size of 2.99 mm^2 and the distance of 2 mm between OLED and OPD.

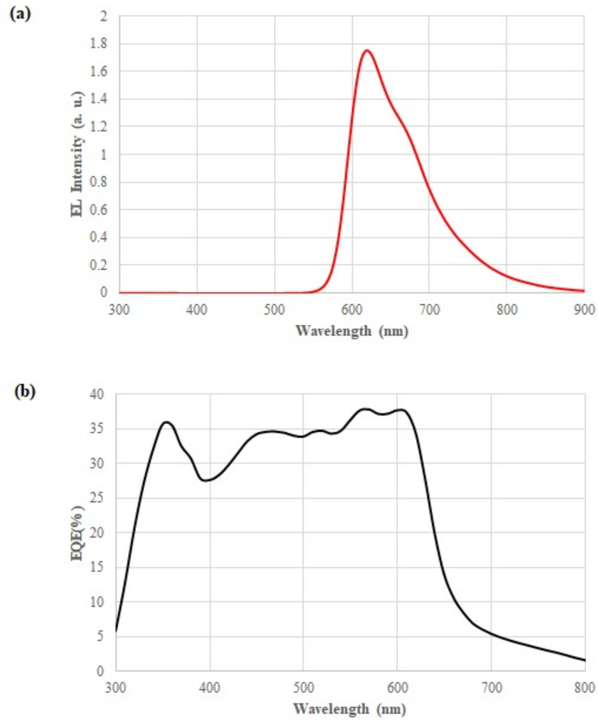


Fig. 9. (a) The OLED's electroluminescence spectrum with respect to the wavelength (nm). (b) The OPD's external quantum efficiency (EQE) with respect to the wavelength.

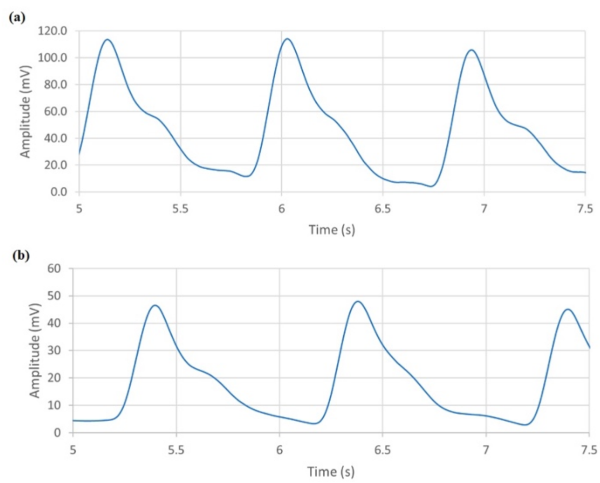


Fig. 10. The PPG signal obtained from (a) Device-1 and (b) Device-2.

Table 2. Signal quality for both devices.

Source (µA)	Device	SNR (dB)
93.6	Device-1	45
	Device-2	46
2.4	Device-1	18
	Device-2	8

Table 2 shows the signal quality from both devices at different current source. The signal-to-noise (SNR) for both devices at higher current show a very small difference at 93.6 μA. It shows that the shorter distance will has a possibility to increase the DC noise of the OPD which then will reduce the SNR value at higher current source. However, the SNR from Table 2 at lower current source shows a significant difference between both devices. At 2.4 μA, Device-1 which has shorter distance between OLED and OPD gives an acceptable SNR of the PPG signal of 18 dB and only 8 dB for the Device-2. It shows that the shorter distance between OLED and OPD gives better SNR value when considering with the power or current source for the device.

Even tough closer distance between OLED and OPD gave better results at lower current source, the SNR was still at lower value compared with the higher current source. Higher current source produced more light intensity and irradiance which then probably gives better SNR value. In this case, the Device-2 pattern will most probably give better SNR value compared with Device-1 based on the results from Table 2. Although the difference was very small but there is still a possibility that the SNR for Device-2 will increase greater than Device-1. This assumption was made due to the possibility of the unwanted reflected light from the other components of the skin will saturated the OPD and blocking the actual signal reflected from the blood especially for the Device-1. In this case, the closer the distance between OLED and OPD also will increase the possibility of direct illumination from the OLED itself to the OPD. In order to improve this device, new structure need to be considered so that the closer distance between OLED and OPD can be realize such as by adding a blocking layer or component between them. By doing this, the direct illumination factor can also be eliminated and further increase the signal quality of Device-1.

4. CONCLUSION

The reflection type was proposed at the beginning of the study due to the fact that it can be applied on any part of the human body compared with the transmission type which is usually can be use at limited number of location such as fingertip, earlobe and toe. The data obtained from the simulations showed that the reflection type has higher signal detection compared with the transmission type. The signal detected for the finger model structure for the reflection was 3.1×10^{-11} A/mm^2 and higher compared with the transmission type which was 6.8×10^{-13} A/mm^2. By increasing the distance between the source and detector will decrease the signal detection.

As for the experimental results, Device-1 shows an acceptable signal to produce the PPG signal compared with Device-2 which has larger distance between OLED and OPD at lower current source which then brings to the probability for fabricating a power saving device for the wearable pulse meter device in the future. In order to increase the signal detection, several factor also need to be considered for further study such as adding the blocking layer between OLED and OPD to eliminate the direct illumination from the source to the detector. Other factors such as size of OLED and OPD areas also will plays an important role to further enhance the signal detection for pulse detecting device in the future.

5. REFERENCES

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