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Can LIDARs address skin color bias?

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Abstract: We evaluated fundamental properties of time-domain near-infrared spectroscopy to overcome color bias in NIRS devices. The Monte Carlo simulations, phantoms, and preliminary in vivo pseudo phantom-human measurements demonstrate how the effect of the superficial layer (skin color layer) can be eliminated to achieve bias-free sensing. © 2024 The Author(s)

1. Introduction

Skin color (racial) bias in non-invasive optical biomarkers (e.g., arterial blood saturation SpO2, heart rate, hydration, body temperature, glucose etc) Sensing (OBS) devices (e.g., Pulse oximeter, smartwatches, glucose, hydration monitors etc) is an unsolved problem spanning three decades. The most widely used OBS device is the pulse oximeter. Despite 40+ years since its introduction and recommended use in critical clinical settings, pulse oximeters are unreliable and suffer from skin color bias and inaccuracies [1]. The racial bias phenomenon was identified as early as in the 90s, and despite efforts, the bias continued [2]. During the covid-19 pandemic, backed by multi-clinical trials, racial bias in pulse oximeters was suspected to have contributed to the loss of many lives, especially in people of color [3]. The key believed contributors to skin color bias and inaccuracy in CW devices are i) multilayer nature of skin tissue, concentration and wavelength-dependent absorption of melanin ii) higher attenuation of light in darkly pigmented skin iii) coupling of absorption and scattering contribution in the detected dynamic (pulsating blood) optical signals [4]. The complex multilayer anatomy of skin and variation across different skin types, ethnicity, and limited research in understanding the effect of skin variables on dynamic optical signals poses challenges to address color bias.

In this work, we propose a novel approach based on time domain near infrared spectroscopy (TDNIRS) to overcome the effect of superficial layer which contributes to skin color bias in continuous wave NIRS devices. We investigate color bias with simulations, measurement on phantom models which shows promising results to overcome superficial layer contribution. We demonstrate the bias free sensing on in vivo pseudo phantom-human at wrist location.

2. Concept, simulation, experimental results

In TDDOS, the pTOF curve generated by the interaction of pulsed laser in tissue naturally distinguishes the coupling of absorption and scattering of multilayers [5]. To be precise, as shown in Fig. 1, the absorption of the superficial layer (melanin pigmentation) affects only the overall attenuation of the pTOF curves. The deep tissue absorption affects the slope of the pTOF. The scattering affects the peak position and broadening of the pTOF. The simulation was built using Monte Carlo Extreme-MCX [6] to simulate a two-layer (skin, muscle) model with realistic optical properties (absorption and scattering of 2 layers) of the human wrist location at 780 nm wavelength, a 7 layer skin model using a time domain white monte carlo based on CUDA MCML was also explored.

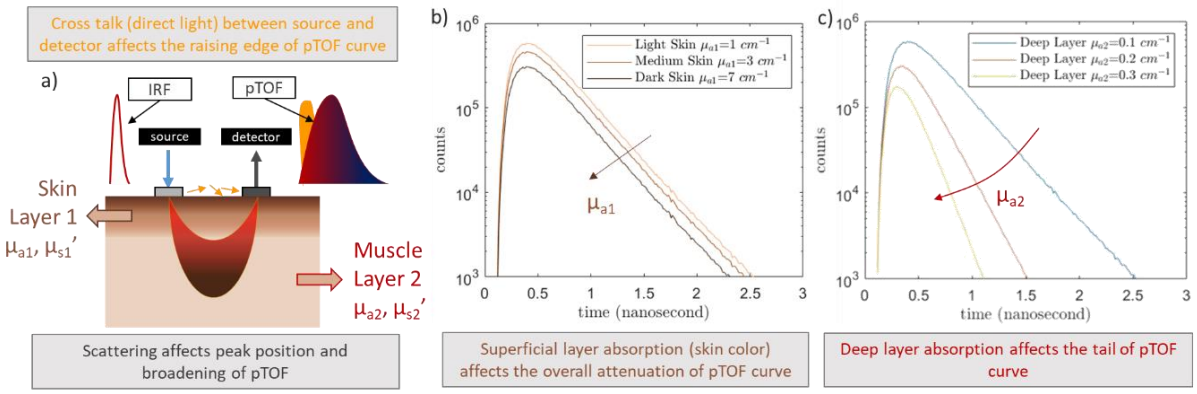
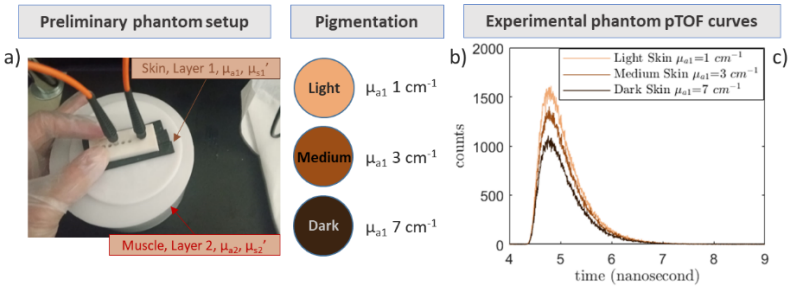


Fig. 1: Principles of bias-free multilayer TDDOS technique proposed by NOBIAS, preliminary PI's simulation of two-layer human wrist skin model showing a) skin pigmentation affects the overall pTOF counts b) Muscle layer affects the slope of the tail of pTOF

The thickness of the superficial layer (skin color) was chosen to be 100 µm (mimicking the epidermis layer containing melanin skin pigment). The bottom layer thickness was around 50 mm mimicking a semi-infinite layer of muscle. The simulation was performed in reflectance geometry (Fig. 1a). In Fig. 1b, the absorption (µa1) of skin color layer was varied from light (Caucasian skin, µa1= 1 cm^{-1}) to medium (Brown skin, µa1= 3 cm^{-1}) to dark (Black skin, µa1= 7 cm^{-1}), realistic values were taken from literature [7]. The absorption of the bottom layer (muscle) was kept constant at µa2= 0.1 cm^{-1}. The results show that the skin layer absorption variation affects overall attenuation not the shape of pTOF. In Fig. 1c, the skin layer absorption was kept constant (Caucasian skin, µa1= 1 cm-1) and the muscle layer absorption was varied over µa2= 0.1, 0.2, 0.3 cm^{-1}. The deep layer (muscle) absorption affects the tail (shape) of pTOF.



Skin color	CW equivalent (a.u.)	pTOF Recovered muscle absorption μ_{a2} (cm^{-1})	pTOF overall Scattering μ'_s (cm^{-1})
Light	320	0.103	9.2
Medium	272	0.104	9.2
Dark	216	0.105	9.3
error	20%	1%	1%

Fig. 2. Bias-free feasibility results on phantoms a) experimental setup of two-layer phantom and TDDOS probe b) pTOF curves of the two-layer phantom with changing skin color (light, medium, dark) layer c) preliminary bias-free extraction of deep layer absorption with varying skin pigmentation, changing the pigment of skin layer does not affect the estimated deep layer (muscle) absorption (μ_{a2})

The simulation results are further backed by experimental results on realistic two layers (skin, muscle) tissue-mimicking phantoms (Fig. 2a). Measurements were performed using laboratory based and wearable TDNIRS device [8]. The top layer absorption was changed across 3 skin color types (light, medium, dark with equivalence µa1= 1, 3, 7 cm^{-1}, respectively) and the muscle layer was kept constant at µa2= 0.1 cm^{-1}. The pTOF curves of the 3 skin color configuration are shown in Fig. 2b. The preliminary recovered optical properties results using a novel multilayer model is shown in Fig. 2c. From the results, it is evident that changing the absorption of the skin layer affects only the CW technology equivalent (the attenuation changes by 20%) signal whereas the recovered muscle layer absorption is independent of variation in the skin layer. These measurements were repeated on human volunteer tissue by performing a pseudo skin color variation measurement. For this, the layer 2 was replaced with wrist location of Caucasian volunteer (simulating low melanin) with different skin color phantoms on top of wrist as layer 1. The results were similar to that of phantom where the effect of skin layer phantom did not affect the measured absorption properties of wrist location.

In this work, we presented the concept of use of TDNIRS to overcome effects of superficial layer like skin color melanin from epidermis layer. The simulation results show that superficial layer affects only the intensity not the shape of pTOF curves. We demonstrated this effect on two-layer tissue mimicking phantoms and on pseudo in vivo human-phantom volunteer. The results show that the estimated absorption values are independent of superficial layer absorption. The wide availability of LIDARs in the market makes the implementation of TDNIRS affordable, with further development of this model we believe the TDNIRS can be provide a bias free alternative to limitations of CW devices for various biophotonics applications (pulse oximetry, cerebral oximeter, wearables, fitness monitors).

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4. References

[1] P. O. Accuracy, "Pulse Oximeter Accuracy and Limitations: FDA Safety Communication How to take a reading: Recommendations for Health Care Providers," 1–4 (2022).
[2] A. Jubran, "Pulse oximetry [6]," Intensive Care Med. 31(11), 1598 (2005).
[3] E. G. Price-Haywood, J. Burton, D. Fort, and L. Seoane, "Hospitalization and Mortality among Black Patients and White Patients with Covid-19," N. Engl. J. Med. 382(26), 2534–2543 (2020).
[4] M. D. Keller, B. Harrison-smith, P. Chetan, and M. S. Arefin, "Skin colour affects the accuracy of medical oxygen sensors," Nature, NEWS & VIEWS FORUM (October 19, 2022).
[5] Konugolu Venkata Sekar, S. et al., A. Broadband Time Domain Diffuse Optical Reflectance Spectroscopy: A Review of Systems, Methods, and Applications. Appl. Sci. 2019, 9, 5465. https://doi.org/10.3390/app9245465
[6] Q. Fang et al., "Accelerating mesh-based Monte Carlo method on modern CPU architectures.," Biomed. Opt. Express 3(12), 3223–30 (2012).
[7] A. N. Bashkatov et al., "Optical properties of skin, subcutaneous, and muscle tissues: A review," J. Innov. Opt. Health Sci. 4(1), 9–38 (2011).
[8] S. Konugolu Venkata Sekar et al.,"Broadband (600-1350 nm) Time-Resolved Diffuse Optical Spectrometer for Clinical Use," IEEE J. Sel. Top. Quantum Electron. 22(3), (2016).