A FINITE ELEMENT APPROACH FOR MODELING LIGHT TRANSFER IN BIOLOGICAL MEDIA USING THE P1/3 APPROXIMATION

Sergey A. Dolgushin [1*], Sergey A. Titenok[1], Jorge Bouza Domínguez [2]

[1]National Research University of Electronic Technology, Shokin sq. 1, Moscow, 124498, Russia
[2]Bishop's University, 2600 Rue College, Sherbrooke, QC J1M 1Z7, Canada

There has been intense activity in the last decade in pursuing light propagation models more accurate than the standard diffusion equation (DE). Recently, novel and more accurate diffusion models have been proposed. Nevertheless, these models provide significant errors when employed on retrieving optical coefficients for thin scattering slabs of biological media [1].

In this work, a finite element – finite difference approach for modeling light propagation in biological media based on the time-dependent $P_{1/3}$ equations is employed as a cost-effective alternative to the standard diffusion equation (DE). An integro-differential equation and corresponding boundary conditions are derived after simplifiying the combined $P_{1/3}$ equations, hereafter called the $SWAP_{1/3}$ model (SWA stands for scalar wave). The $SWAP_{1/3}$ model preserves the causality principle and predicts that the light wave propagates in the medium at the correct light speed value, in contrast to the classic standard scalar wave equation obtained from the P_1 equations. To study the $SWAP_{1/3}$ numerical approach's performance for complex media, several numerical experiments with slab geometries are conducted. The geometries mimic three-dimensional sections of biological tissue with varying thickness d from d = 0.5 cm up to d = 4.0 cm. For comparison, Monte Carlo simulations and DE numerical solutions for the same aforementioned media are included in the study.

It is observed that the proposed numerical approach of the $SWAP_{1/3}$ model better reproduces the Monte Carlo simulations' results than the DE results in most experimental cases. Hence, the hypothesis that the proposed numerical approach could have a superior performance than numerical solutions of the DE as a forward model in the solution of inverse problems in optical imaging is supported. These results are considered as a step forwards in the common use of non-parabolic analytical models that can better reproduce transport calculations.

Although progressive studies should be carried out with the $SWAP_{1/3}$ numerical approach, these work results are considered as a step towards the use of non-diffuse, non-parabolic analytical models in forward and inverse problems of biomedical optics. It is the intention of the authors to carry out with these studies and further motivate the community in the field. This work was financially supported by the Ministry of Science and Higher Education of the Russian Federation (agreement № 14.584.21.0021, identificator RFMEFI58417X0021).

[1] Tereshchenko, S. A., Dolgushin, S. A., Titenok, S. A., “An imperfection of time-dependent diffusion models for a determination of scattering medium optical properties,” Optics Comm., 306(1), 26–34 (2013).

* Corresponding Author: dolgushin.sergey@gmail.com