BIOPHOTONICS – EXERCISE 2: LIGHT-TISSUE INTERACTION WITH MONTE CARLO SIMULATION

1 General Information

Please prepare the task until the deadline provided. Please upload your solution via Digicampus. Make sure that the following requirements are met:

- Hand in the experiment protocol as PDF
- The experiments and tasks, as well as results should be comprehensible from the protocol without having to consult this task assignment!
- List your sources!
- All source code must be available and executable for us (this implies that you specify the required packages; in addition, you have to provide necessary data and/or give advises if paths have to be adjusted; in order to do so, you should provide a reasonable README file).

Submission deadline is Sunday, 08.12.2024, 23:59.

Please ask in case of any doubts regarding the contents or the formal procedure.

2 Background on the exercise

Being able to model the interaction of light and tissue is crucial for the research of optical methods of skin perfusion assessment. Not only rely systems as photoplethysmography (PPG) or oxygen saturation measurement on the absorbance and reflectance of light within tissue, but future developments of new diagnostic techniques also require knowledge and predictability of the underlying optical effects.

Using the Monte Carlo method, it is possible to simulate the paths of photons through layers of different materials.

In this exercise you will research the composition of skin layers and their optical properties and learn about the Monte Carlo Simulation. You will use this knowledge to simulate the propagation of photons and absorbance of light as it travels through different layers of skin.

3 Task(s)

Before starting to set up the simulation environment, start with describing your model:

- Research the composition of the human skin
- Define a simple skin model consisting of 3 different layers (Epidermis, Dermis, Subcutis) and a total thickness of minimum 0.3 cm.
- Research the optical properties of your layers for green light

(1) Show and describe your over-all model and needed properties. The following simulations will build on this model. Remember to state the source of your information.

(2) Choose your simulation environment. Then simulate the propagation of photons (green) into your model and present two 2D projections (side and upfront) of the energy distribution.

Depending on the application one has to choose the correct wavelength to be able to observe the effects of interest. Different wavelengths penetrate deeper into tissue and have varying absorbance coefficients depending on cell types and materials. For the next tasks, retrieve the optical properties for blue, red and near-infrared light (NIR) as well.

(3) Simulate the propagation of blue, red and NIR light and present comparing 2D projections. Using the 1D depth energy profile, compare the penetration depth and absorbance to the green colour used in the previous simulation. For each colour state at which depth 50% and 90%, respectively, of the emitted energy is lost and to which tissue layer such depth corresponds to.

(4) Increase the thickness the outer layer in your model and evaluate the effect on blue, green, red and IR photons based on the 1D energy profile.

For the applications like reflectance PPG, the backscattered light is of great interest. Find a way to view the amount of energy leaving your model at the surface.

(5) Visualize the amount of energy leaving the surface in direction to your light source for different light colours (green, blue, IR).

Research the optical properties of oxygenated blood. Modify your model and split your middle layer into two parts, then add a layer of blood in between.

(6) State your blood’s optical properties and present the final model.

(7) Show the 2D and 1D energy projections for green, blue and IR light.

(8) Compare the amount of energy leaving the surface against your results from (5).

4 References (and recommended reading)

[1] https://github.com/DCC-Lab/PyTissueOptics
[2] https://github.com/xopto/pyxopto
[3] Steven L. Jacques, "Tutorial on Monte Carlo simulation of photon transport in biological tissues [Invited]," Biomed. Opt. Express 14, 559-576 (2023)
[4] A. Bhandari, B. Hamre, Ø. Frette, K. Stamnes, and J. J. Stamnes, "Modeling optical properties of human skin using Mie theory for particles with different size distributions and refractive indices," Opt. Express 19, 14549-14567 (2011)