The Monte Carlo method to simulate the trajectories of a large number of photon packets on a multilayer biotissue

Authors

Izabella A. Serebryakova[1]
Yanwen Xu[2]
Qing Xia[2]
Dongyu Li[2]
Dan Zhu[2]
Yuriy I. Surkov[1]
Elina A. Genina[1,3]
Valery V. Tuchin[1,3,4]

Affiliation

[1]Saratov State University, Russia
[2]Huazhong University of Science and Technology, Wuhan, China
[3]Tomsk State University, Russia
[4]Institute of Precision Mechanics and Control, FRC "Saratov Scientific Centre of the RAS," Russia

Contacts

Email: s.izabell2014@gmail.com
Tel: 8 951 885 83 69

Introduction

Understanding how photons propagate within and escape from a tissue is necessary for proper interpretation of optical diagnostic measurements. The field of biomedical optics and biophotonics is currently very actively using computer simulations of light transport to guide clinical protocols and develop optical tools for medicine and biology

➢ The program simulates the trajectories of photon packets through a multi-layered medium, taking into account absorption, scattering, and transmission processes

➢ The simulation is performed for 100 000 photon packets, and the positions of each photon packet are recorded

Skin layer	Thickness, μM	Refractive index [n]	absorption coefficient [μa]/cm[1]	scattering coefficient [μs]/cm[1]	Anisotropy factor [g]
Stratum corneum	10	1.50	0.15	175.0	0.90
Living epidermis	100	1.34	2.47	87.5	0.80
Dermis	4000	1.40	0.28	80.6	0.82

Concepts

➢ **Photon Step Size Calculation:**
The distance t that a photon travels in a given layer before an interaction (absorption or scattering) is determined by:

$$t = -0.05 \cdot \frac{ln(r)}{\mu_a + \mu_s}$$

where r is a random number between 0 and 1
μ_a is the absorption coefficient,
μ_s is the scattering coefficient

➢ **Probability of Absorption vs. Scattering**
The probability of a photon being absorbed or scattered is determined by the ratio of the absorption coefficient to the total interaction coefficient:

$$P_{absorption} = \frac{\mu_a}{\mu_s + \mu_a} \qquad P_{scattering} = \frac{\mu_s}{\mu_s + \mu_a}$$

➢ **Scattering Angle Calculation:**
The scattering angle θ is determined using the Henyey-Greenstein phase function:
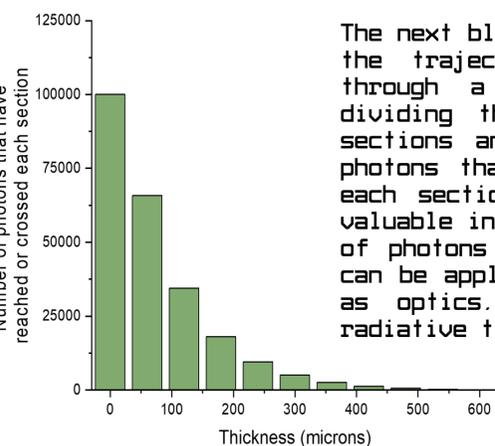
$$0 = \arccos\left(\frac{1-g^2}{1-g+2g \cdot r}\right)$$

where g is the anisotropy factor,
r is a random number between 0 and 1

➢ **Azimuthal Angle Calculation:**
The azimuthal angle φ is randomly chosen between 0 and 2π

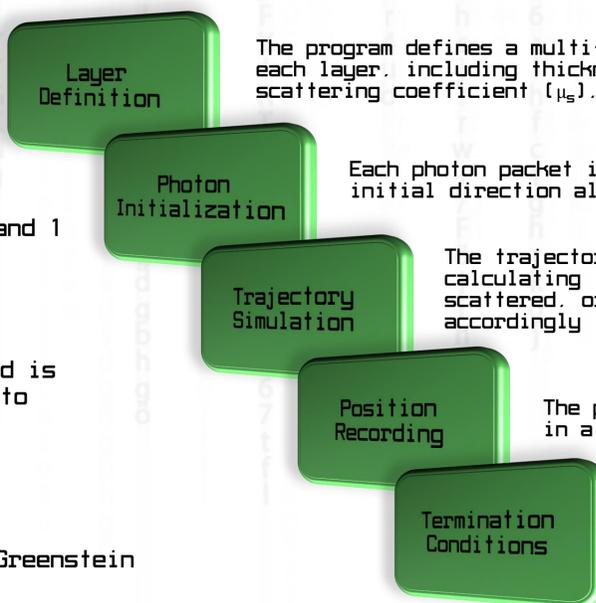$$\phi = 2\pi \cdot r$$

Segment analyzes the trajectories

The next bloc program segment analyzes the trajectories of photon packets through a multi-layered medium by dividing the medium into predefined sections and counting the number of photons that have reached or crossed each section. This analysis provides valuable insights into the propagation of photons through the medium, which can be applied in various fields such as optics, biomedical imaging, and radiative transfer.

Program Functionality

Layer Definition
The program defines a multi-layered medium with specific optical properties for each layer, including thickness, refractive index [n], absorption coefficient [μa], scattering coefficient [μs], and anisotropy factor [g]

Photon Initialization
Each photon packet is initialized at the center of the first layer with an initial direction along the z-axis

Trajectory Simulation
The trajectory of each photon packet is simulated by iteratively calculating its step size, determining whether it is absorbed, scattered, or transmitted, and updating its position and direction accordingly

Position Recording
The positions of each photon packet are recorded and stored in a list for further analysis or visualization

Termination Conditions
The simulation of a photon packet's trajectory is terminated if the photon is absorbed, if it leaves the defined spatial boundaries, or if it exits the multi-layered medium
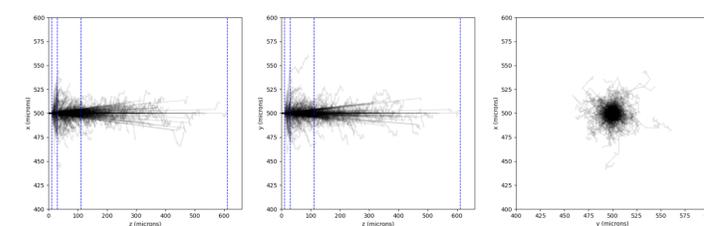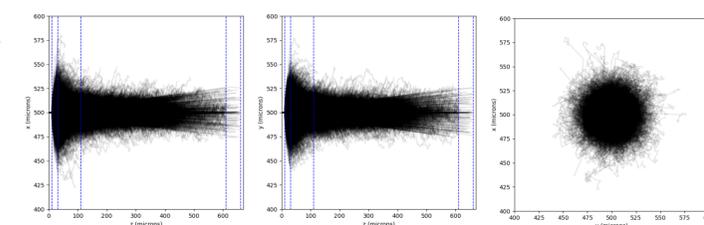
Visualization

3D Plot of Photon Trajectories
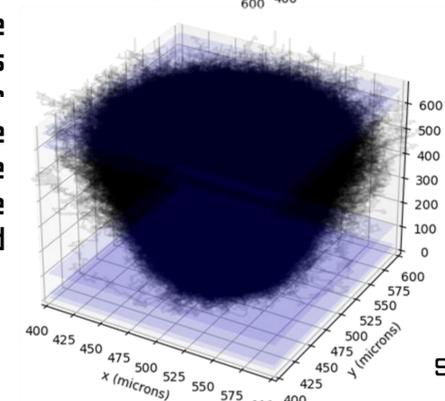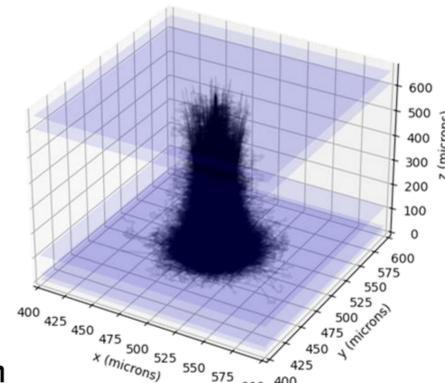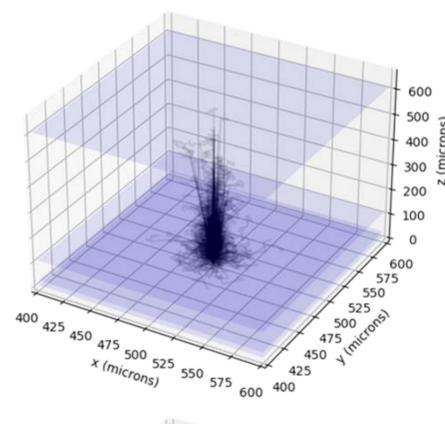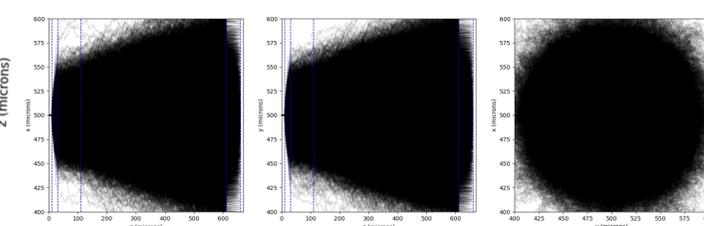
2D Plots of Photon Trajectories

The x, y, and z coordinates of the photon packets, represented as semi-transparent black lines. Lines and planes to separate the layers, with the z-coordinates corresponding to the cumulative thicknesses of the layers

Simulate the trajectories of 1 000 photon packets

Simulate the trajectories of 10 000 photon packets

Simulate the trajectories of 100 000 photon packets

Conclusion

The program saves the simulated photon trajectories to text files, visualizes these trajectories in both 3D and 2D plots, and saves the input parameters of the simulation for future reference. The visualizations include clear demarcations of the layers within the medium, providing a comprehensive view of the photon propagation through the multi-layered structure