A Monte Carlo simulation based on Mie theory to describe light propagation through a highly scattering random medium

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Abstract
Mie theory [1] describes the elastic scattering of light by particles which are modeled as homogeneous spheres. It is based on the solution to Maxwell’s equations which was developed by Gustav Mie in 1908. Mie theory is very useful in situations where the size of the scattering particles is comparable to the wavelength of the light, rather than much smaller or much larger. It may be used to approximate the scattering behavior of biological tissues, and to develop light transport models for imaging through biological tissues.

Our work is primarily focused on network scatter events, where Mie scattering happens multiple times as photons propagate through a large network of spherical scatterers. The latter is done by using Monte Carlo simulations in which many photons are launched and traced as they propagate through a scattering medium. Each photon undergoes a random walk process comprised of multiple single scattering events. The direction of a photon after scattering is a random value generated using the angular probability distribution based on Mie scattering. An open-source set of programs were designed to simulate Mie scattering for various types of scattering media. Christian Matzler’s 2002 MATLAB code [2] on single scatter served as the foundation which was built off for the coding.

Mie Scattering and Monte Carlo Simulations
- Light scattering: processes where light waves deviate from their projected trajectory by interacting with localized non-uniformities or measurable changes with respect to the propagation medium
- Mie Scattering: light scattering where scatterer radius greatly exceeds incident wavelength
- Modeling Mie Scattering is vastly more arithmetically and computationally intense to simulate than other types of light scattering
- Single scatter simulations and multiple scatter simulations refer to the number and arrangement of scattering media
- Monte Carlo simulations: methodologies which simulate complex, theoretically deterministic behavior through random sampling of a very large sample size
- Mie Scattering is characterizable with Monte Carlo Simulations

Mathematical Framework
- All voxels assigned indexes which can be used to discern information about relative position and photon density
- The number and size of voxels is user-determined
- Scattering angles in 3D space use (φ, θ)
- Use of 2 coordinate systems to track photon trajectories and position
- Global coordinate system to track information relative to a fixed point in our scattering media
- Local coordinate system which is defined relative to the most recent scatter. Our code can translate information from one coordinate system to another

Simulation Framework
- Series of MATLAB/Octave programs allowing us to simulate certain attributes of Mie Scattering
- Break down our scattering media into voxels, cube-shaped regions of space
- Designed to contain one and only one scatterer per voxel

Results

Conclusions
It is difficult to succinctly characterize our findings because of the large quantity of data which can be recorded. However, some key observations are as follows:
- Mie single scatter events had extremely asymmetrical intensity functions, while Rayleigh single scatter events possessed near-symmetrical intensity functions
- In the case of boundary reflection events, even the addition of a relatively modest probability of reflection can drastically increase runtime of the simulation, meaning photons are propagating in the scattering media for a longer amount of time; one such example could be seen by comparing two otherwise identical networks where one had a fixed 80% probability for reflection under boundary conditions; photons remained within the system for roughly an order of magnitude longer
- Peak photon density decreased, and photon spread increased the farther into our scattering media we were

References