Decomposition of volumetric path-tracing for in-water radiative transfer: A hybrid beam, path and forward scattering approach

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Radiative transfer in horizontally-structured natural waters poses unique challenges to simulation and modeling. We discuss the history of using bi-directional ray tracing approaches for the DIRSIG (Digital Imaging and Remote Sensing Image Generation) model, culminating in a technique developed for the latest version (DIRSIG5). It has been specifically designed to work in conjunction with the Monte Carlo method of path-tracing that samples end-to-end scattering paths through a virtual scene at once rather than hierarchically gathering contributions. The novel approach decomposes the solution to the radiative transfer equation into three different elements. The first component uses a geometric beam approach based on the physical structure of the air-water interface for single in-water scattering contributions. The second component exploits the path-tracing framework to expand the solution to all scattering orders. Finally, the third component re-introduces a (partial) direct solution to highly forward-scattering phase functions that are often found in natural waters. We will demonstrate how the solutions to these components overlap computationally in some unexpected ways. The discussion will also include several cross-verifications with the seminal verification cases developed by Mobley (1993) and details of the anisotropic surface BRDF for under-resolved surface effects. We will also present several image and video examples of how the various tools result in an end-to-end modeling capability for phenomenology understanding and con-ops trade states.