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Quasi-Photon Monte Carlo on Radiative Heat Transfer: An Importance Sampling and Learning Approach

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Abstract : At high temperature, radiative heat transfer is the dominant mode of heat transfer. It is governed by various phenomena such as photon emission, absorption, and scattering. The solution of the governing integrodifferential equation of radiative transfer is a complex process, more when the effect of participating medium and wavelength properties are taken into consideration. Although a generic formulation of such radiative transport problem can be modeled for a wide variety of problems with non-gray, non-diffusive surfaces, there is always a trade-off between simplicity and accuracy of the problem. Recently, solutions of complicated mathematical problems with statistical methods based on randomization of naturally occurring phenomena have gained significant importance. Photon bundles with discrete energy can be replicated with random numbers describing the emission, absorption, and scattering processes. Photon Monte Carlo (PMC) is a simple, yet powerful technique, to solve radiative transfer problems in complicated geometries with arbitrary participating medium. The method, on the one hand, increases the accuracy of estimation, and on the other hand, increases the computational cost. The participating media -generally a gas, such as CO_2, CO, and H_2O- present complex emission and absorption spectra. To model the emission/absorption accurately with random numbers requires a weighted sampling as different sections of the spectrum carries different importance. Importance sampling (IS) was implemented to sample random photon of arbitrary wavelength, and the sampled data provided unbiased training of MC estimators for better results. A better replacement to uniform random numbers is using deterministic, quasi-random sequences. Halton, Sobol, and Faure Low-Discrepancy Sequences are used in this study. They possess better space-filling performance than the uniform random number generator and gives rise to a low variance, stable Quasi-Monte Carlo (QMC) estimators with faster convergence. An optimal supervised learning scheme was further considered to reduce the computation costs of the PMC simulation. A one-dimensional plane-parallel slab problem with participating media was formulated. The history of some randomly sampled photon bundles is recorded to train an Artificial Neural Network (ANN), back-propagation model. The flux was calculated using the standard quasi PMC and was considered to be the training target. Results obtained with the proposed model for the one-dimensional problem are compared with the exact analytical and PMC model with the Line by Line (LBL) spectral model. The approximate variance obtained was around 3.14%. Results were analyzed with respect to time and the total flux in both cases. A significant reduction in variance as well a faster rate of convergence was observed in the case of the QMC method over the standard PMC method. However, the results obtained with the ANN method resulted in greater variance (around 25-28%) as compared to the other cases. There is a great scope of machine learning models to help in further reduction of computation cost once trained successfully. Multiple ways of selecting the input data as well as various architectures will be tried such that the concerned environment can be fully addressed to the ANN model. Better results can be achieved in this unexplored domain.

Keywords : radiative heat transfer, Monte Carlo Method, pseudo-random numbers, low discrepancy sequences, artificial neural networks
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