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MODERN METHODS OF PARTICIPATING MEDIA RENDERING

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ABSTRACT. The paper observes modern methods of participating media rendering. Were identified their pros and cons as well as the tendency of deep learning integration for solving actual rendering problems.

Introduction. Creation of a physically accurate image of participating media is one of the most challenging tasks in computer graphics. Obtaining close to the reference results of the volume rendering equation calculation is computationally expensive and practically impossible in real-time. With the emergence of the new approach of participating media rendering [1] the synthesis of photorealistic images in real-time became feasible.

Objectives. The aim of the work is to examine modern methods of participating media rendering, identify their strengths and weaknesses, determine the possible direction of further development in creating photorealistic and physically accurate images of participating media.

The main part. Participating media is a material, property of which affects the transfer of light through its volume. A medium is considered participating if it absorbs, emits, or scatters a ray as it passes through the medium.

Participating media rendering comes down to the solution of the volume rendering equation, which describes the radiance of the ray L that passes through the point x in the direction ω, taking into account the outgoing radiance from the surface L_o at the end of the ray, and can be represented as follows:

$$L(x,\omega) = \int_0^z T(x,y)[\mu_a(y)L_e(y,\omega) + \mu_s(y)L_s(y,\omega)]dy + T(x,z)L_o(z,\omega)$$

The most important parts of the equation are transmittance T and in-scattered radiance L_s. Each point on the ray along which we need to integrate is described by y.

Participating media rendering methods can be divided into two groups: offline and real-time. The goal of offline methods is to create a physically accurate image with as little variation from the reference as possible by carefully calculating volumetric light transport. The expected result of real-time methods is the synthesis of a physically plausible image in no more than 41.6 ms for rendering the entire frame, which is possible due to various optimization methods of the light ray passage through the participating medium.

In 2021, the State Key Lab for Novel Software Technology of Nanjing University presented a development for discrete participating media that allows not only to significantly improve the rendering time but also to considerably expand the range of particles that can be handled in comparison with standard path tracing [2]. This result was made possible by applying the geometric optics approximation and solving the volume rendering equation based on it. Unfortunately, this method has difficulties in rendering non-spherical particles and cannot work with a spatially correlated material.

With the aim of ensuring real-time rendering of participating media, other approaches are used. For example, to render a physically plausible image of large-scale quasi-heterogeneous participating media, the screen space method can be used in a post-processing step [3]. The developed hierarchical anisotropic filtering contributes to the photorealistic image, and the analytical solution of the density integral reduces computational costs. However, this method has several problems, such as flickering in certain rendered scenes and ignoring volumetric occlusions.

Activision company, in turn, published a method based on pre-calculation of volumetric transport from a participating medium to a surface and baking it into a lightmap [4]. Light transport is represented as spherical impulse responses parameterized by zonal harmonics. The method can work with a heterogeneous medium, supports multiple scattering, and an image produced in real-time is similar to that synthesized by path tracing. The disadvantages consist of ignoring scattering around occluders in a medium, and an average 10% increase of light baking time.

In the meantime, Nvidia has been for several years investigating the use of deep learning to improve the quality of an image obtained in real-time. One example of successful implementation is Deep Learning Super Sampling (DLSS) anti-aliasing technology. In 2021, Nvidia applied deep learning to denoise an image and guide ray samples in path tracing rendering of participating media, which resulted in an image synthesized with 4 rays per pixel similar to that with 4096 rays per pixel. Despite significant reductions in computational costs, the method works in real-time only on the latest generation GPUs and on scenes with a medium of small volume. Also, the utilized neural network requires retraining for specific cases.

The next table presents the summary of the methods' pros and cons.

Table 1 – advantages and disadvantages of participating media rendering methods

Method	Advantages	Disadvantages
Rendering Discrete Participating Media with Geometrical Optics Approximation	Decreases rendering time and expands the range of handled particles compared to path tracing	Cannot support non-spherical particles and a spatially correlated material
Real-time Light Transport in Analytically Integrable Quasi-heterogeneous Media	Operates fully in real-time, has a physically plausible output	Flickers on some scenes, ignores volumetric occlusions, supports only analytically solvable density of a medium
Impulse Responses for Precomputing Light from Volumetric Media	Operates fully in real-time with output close to one synthesized by path tracing	Ignores scattering around occluders, increases required preprocess time
Interactive Path Tracing and Reconstruction of Sparse Volumes	Can operate in real-time with output quality similar to path tracing	For now, is too computationally complex, in some cases utilized neural network requires retraining

Based on the held study, the following perspectives of the considered methods can be anticipated. Offline methods remain the standard in cinematography, since only they can produce an image as close as possible to the reference without losing the necessary details. Real-time methods for the mass market are not possible nowadays to fully replace with more accurate methods using deep learning due to the still high computational requirements. However, given the rapid development of technologies and streaming services, that take over most of the computation, one can increasingly observe the displacement of existing approaches by the utilization of deep learning in computer graphics, which will provide a better output than existing handcrafted algorithms.

Conclusions. Along with traditional participating media rendering methods capable of delivering high-quality results not only offline but also in some cases even real-time, a new direction is emerging for solving the same problems or parts of them through the use of deep learning. This direction still has certain drawbacks and cannot entirely replace the methods used today, but there already are examples of its successful introduction.

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