Rendering Particles in a Shaft of Light using Tyndall Effect

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Figure 1: *Goal : Natural glowy effects attenuating from light sources and shafts of light. Visualization of moving particles.*

Abstract

In real life, we often face some lighting situations where glowy effects are produced by light sources where there are many visibly big particles. Using functions in existing shading languages or built-in functions in graphics hardware can only generate rather artificial images because it does not consider scattering. Previous works have proposed similar lighting effects. However, most are based on the general scattering situations where the particles are far smaller than wave lengths. In this paper, we propose natural lighting effects for similar sizes of particles to visible wave lengths, tyndall effects. We use simplified mie theory that can visualize the effect and combine it with simplified single scattering theory proposed by [Sun et al. 2005]. Using this technique, it is possible that it will render such an effect somewhere close to real-time.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Radiosity;

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1 Introduction

When raining, everything is looks darker than it normally does without raining. This is because of the physical phenomenon, scattering. The scattering of light, especially inelastic scattering, makes color to spread in certain or uncertain ways. Many graphics applications such as games and animation sometimes need to render mist and fog. Many computer graphics research works have proposed practical model for single and multiple scattering related to such foggy effects. Due to multiple scattering in these participating media, to achieve realistic looks in the scene, shading should lose its colorfulness and also have glowy effects around light sources. For light passing through visible participating media in some cases, we should be able to see glowy particles with specularity, not just glowy air since scattering comes from each particle. Unfortunately, it is very challenging to render not only naturally attenuating lighting effect and but also particle effects due to scattering given its complexity of the diffuse process in the case of rendering scattering from each particles.

In this paper, we attempts to render particle-based effects based on Mie theory which applies when scattering media have similar sizes to wavelengths of the light. We also expedite the technique by using and Fraunhofer approximation based on particular particle materials. we combine the real-time single scattering model from [Sun et al. 2005] with Fraunhofer approximation to render a scene where around light is glowy. Our technique also generates a particle map that allows the visualization of direct single scattering from each particle. This particle map allows irregularity on the lighting glows so that it will look like tyndall effects where visibly big particles reflect lights.

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2 Related Work

Starting from [Blinn 1982], there have been numerous research papers based on analytic functions using light scattering theories. [Blinn 1982]'s method is statistics based, however, it could be better to incorporate physical model more directly. [Kajiya and Von Herzen 1984] uses single scattering. They separate high and low albedo cases and provide approximation for high albedo because of the characteristics of cloud where complex multiple scattering effects commonly occur. They also extend it to use on spherical harmonic. [Division] proposed a method that works for the situation where viewers are immersed in the participating media. Its case matches ours. Therefore, we loosely follow this model. [Ertl et al.] developed further their previous method to more accurately render shadows and decrease the dimensions of maps for memory and optimization. It does not consider natural attenuation of light shafts based on the distance between the pixel and the center of the light shafts although the rendered light shafts themselves can be inherently soft. Also, multiple scattering effects through non-homogeneous media was generated in a full monte carlo simulation in [Jensen et al. 2001]. [Max 1986] modified the scanline and followed [Crow 1977] to visualize shadow. Another work that assumes that the viewer is in the homogeneous participating media involves [Narasimhan and Nayar 2003]. This method shows a model that works in general for many different participating media situation(haze, fog, mist, rain). The authors first derive multiple scattering scheme model from an isotropic light source. they use the fact that Radiative Transfer Equation(RTE) can be used to solve it at any point in the atmosphere. However, multiple scattering model may not be suitable for interactive models due to its complexity. [Dobashi et al. 2000] proposed an interactive model for rendering a shaft of light using volumetric structures. By successfully getting Riemann sum, it generates a naturally soft shaft of light. Thus, it is easy to visualize non-uniform density of particles. Although it can lead to a more realistic scene, it may also have hole problems and thus require to fill the holes. This technique is ideal for our method since this method uses volume, which inherently allows us to render different distribution of particles. It can be prone to little artifacts based on the number of planes. There is trades-off between the number of planes and the performance. [Baran et al. 2010] visualizes shaft of light with natural shadows using linear transformation and pre-filtering. There still may be artifacts. However, the epipolar transformation enables a very plausible shadows in 3D scenes at interactive rates. [Chen et al. 2011] further presents a developed method with min-max data structure, which makes it possible to work very interactively. However, it does not consider natural attenuation of light as the pixel gets far from the center of the light shaft. It does not consider participating media, which can result in an unrealistic image. [Sun et al. 2005] shows a real-time model that visualizes single-scattering in foggy settings. This physically based but simplified model renders a natural and improved light scattering effects. By combining its model with BRDFs and environment mapping, it extends its technique to general use. Because this can be easily extended to general uses and rather simplified compared to more complex model like [Pegoraro and Parker 2009], we further take this to render natural attenuation in shaft of light. [Lecocq et al. 2000] presents a rendering model that works in real-time using mathematical approximation of light transport theory through participating media. As [Pegoraro and Parker 2009] indicates, it can be intractable in some dynamic settings. Therefore, we chose not to use it. [Pegoraro and Parker 2009] presents an analytical model extended from the Airlight model and Radiative Transfer Equation(RTE) in a closed function form. It is applicable in a little dynamic scenes since additional terms based on different variables can be derived from the original scene, and it is not very distinguishable from the reference scene. However, this work is hardly interactive since it may take a few minutes to render a scene. [Kajiya 1986] This paper shows well-suited rendering equation for Computer Graphics from well-known radiative heat transfer literature-Thermal Radiation Heat Trarsfer. Based on the implementation, ray-marching can cause a slow-down. We incorporate it in the ray-marching integral to render lighting effects. [Goral et al. 1984] describes how irradiance from diffuse surfaces cause other objects to light, such as the color-bleeding effect. None of these works except for [Ertl et al.] incorporated the Mie theory in order to render the natural bluish color-effects to visualize sufficient big particles with respect to visible range of wavelengths of light. Also, none of these works have particle movement visualization in the glowy part near light or in the light shafts.

3 Method Overview

1. We get projection of light using a texture map on volumetric planes. [Segal et al. 1992]
2. We first implement volume visualization approach for ray-marching by [Dobashi et al. 2000].
3. We use [Sun et al. 2005]'s airlight model and radiance transfer model to render attenuating light effects as it gets far from the center of the shaft of light.
4. We combine with another effect. We take the Fraunhofer Approximation to approximate the mie theory to render the tyndall effect.

A. It occurs at a random point in accordance with the density that users input.

B. In accordance with the Fraunhofer Approximation, we devise a probability model to determine which direction the diffuse process should take place. The distance between the reflected light transport and the randomly chosen point is also determined by the density of particles given.

C. We attempt to ignore the wave length of light when considering the intensity of the reflected ray.

D. We use single scattering for simplifying our model.

4 Implementation

We use [Segal et al. 1992]'s projection method to define light texture map. We will further take out artifacts in the texture map by defining distribution function instead of using the map. We loop over the texture map so that we can get projection of the map on each volumetric plain parallel to the eye position. (See Projection Model section in Appendix)
Then we further use the volumetric data to do ray-marching. However, when doing it, we use airlight model to store the intensity value.
To visualize particles, we devise the method from Surface radiance model from [Sun et al. 2005]

A Projection Model

$$Q^t = Q^/ w^l \tag{1}$$

$$= \frac{AQ_1^l + BQ_2^l}{Aw_1^l + Bw_2^l} \tag{2}$$

$$= \frac{aQ_1^l/w_1 + bQ_2^l/w_2}{a(w_1^l/w_1) + b(w_2^l/w_2)} \tag{3}$$

Q^t is a point after projection and Q^l is a point before projection. w is a depth to the polygon defined in affine transformation matrix.

B The Fraunhofer approximation in the air

Using the data in Range of validity of the Fraunhofer approximation in the estimation of particle size distributions from light diffraction, it will generate a probability function that defines BRDF and the constant T_{sp}. is defined as

$$T_{sp} = Particle\ density\ \times\ distance\ between\ bouncing\ point\ P\ and\ source \tag{4}$$

C Airlight Model

$$L_a = A_0(T_{sv}, \gamma, \beta) \int_{\gamma/2}^{\frac{\pi}{4}+\frac{1}{2}arctan(\frac{T_{vp}-T_{sv}cos(\gamma)}{T_{sv}sin(\gamma)})} exp[-A_1(T_{sv}, \gamma)tan(\xi)]d\xi \tag{5}$$

D Particle Radiance Model

We incorporate the surface radiance model from [Sun et al. 2005]

$$L_p = I_0 k_d [\frac{e^{-T_{sp}}}{D_{sp}^2} cos(\theta_s) + \beta^2 \frac{G_0(T_{sp}, \theta_s)}{2\pi T_{sp}}] + \tag{6}$$

$$I_0 k_s [\frac{e^{-T_{sp}}}{D_{sp}^2} cos^n(\theta_s^{'}) + \beta^2 \frac{G_n(T_{sp}, \theta_s)}{2\pi T_{sp}}] \tag{7}$$

We modified the model below:

$$L_{pa} = \int_{\Phi} L_p d\Phi \tag{8}$$

$$= \sum^{p} \frac{L_p}{e^p} \tag{9}$$

$$\tag{10}$$

p is the efficiency factor of Mie scattering. Due to the complexity, we set it to a constant.

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