SMC based on Phong's model

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Abstract. A split Monte Carlo algorithm based on Phong's radiation model for the calculation of the impulse response on infrared wireless indoor channels with various reflecting property is presented. It allows evaluation of not only Lambertian-diffuse but also direction-diffuse reflections. The numerical burden can be dramatically reduced with nearly geometric growth in the number of rays compared to classical deterministic algorithm for exponential ray growths.

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[DOI: 10.1117/1.1850692]

Subject terms: infrared wireless communications; split Monte Carlo; impulse response; Lambertian reflection; direction-diffuse reflection.

Paper L040369 received Jun. 13, 2004; revised manuscript received Oct. 31, 2004; accepted for publication Nov. 24, 2004; appeared online Nov. 29, 2004; published online Feb. 1, 2005.

To design a high-performance indoor infrared wireless nondirected data communications system, an accurate estimation of the impulse response is required. This problem can be studied by means of the deterministic¹ algorithm or the statistical approach.² All surfaces in the channel are considered to be Lambertian diffuse reflectors. However, the Lambertian model cannot describe the reflection pattern of many polished surfaces common in the indoor space, e.g., the painted, varnished surfaces and glass, which presents a strong directional-diffuse (DD) reflection besides diffuse or just a simple mirror reflection (MR). Lopez-Hernandez et al.³ considered MR and used a Monte Carlo ray-tracing algorithm to reduce the numerical burden. In their model only one new ray is generated for each reflection. Lomba⁴ and Yang,⁵ respectively, experimentally demonstrated that the empirical Phong's scattering model can effectively approximate any nondiffuse reflection besides MR and as diffuse. Phong's model consists of DD and diffuse reflection components. For an accurate and fast simulation of the impulse response in a real channel, we use a split Monte Carlo (SMC) algorithm to generate two split random rays for each reflection: one diffuse and another DD. Compared with the deterministic algorithm with exponential ray growth, the SMC algorithm with nearly geometrical ray growth can greatly reduce the numerical burden.

First, the surface reflection property, the relevant light source data, and the receiver in the channel are defined. The

intensity profile of the light source may have a shape that is a generalized Lambertian, Gaussian, or uniform, etc. The receiver typically employs silicon p-i-n detectors encapsulated in hemispherical or plano-cylindrical lenses, which provide proper optical gain as well as maintain a wide field of view (FOV). Based on the work of Lomba⁴ and Yang,⁵ the expression of Phong's model to approximate the radiation intensity distribution can be given by

$$I = \rho P_s / \pi \cdot [r_d \cos(\theta_o) + C(1 - r_d) \cos^m(\alpha)] \quad (1)$$

where ρ is the surface reflection coefficient, P_s is the incident optical power, r_d is the percentage of the incident signal that is reflected diffusely, θ_o is the angle between the observation direction vector $\mathbf{v}$ and the surface normal vector $\mathbf{n}$, m is the exponent of the DD reflection, $C = (m + 1)/2$ is the normalization factor, and α is the angle between vector $\mathbf{v}$ and the MR direction vector $\mathbf{u}$ of the incident direction. The first and the second terms in Eq. (1) denote the reflection components of the homogeneous diffuse and DD, respectively. Two corrections are given in Refs. 4 and 5. First, the second term is weighted by factor C to preserve energy conservation. Second, α is substituted for $\theta_o - \theta_i$ (θ_i is the angle between vector $\mathbf{u}$ and $\mathbf{n}$) to extend the applicable reflection range from the primary incidence plane to three-dimensional space. Phong's model can also denote Lambertian when $r_d = 1$ and MR when $r_d = 0$ and $m \rightarrow \infty$, respectively.

We use the light source with a generalized Lambertian radiation intensity pattern as an example. Many starting rays can be generated by using two uniform random parameters μ and ν ($\in [0, 1]$). For a random starting ray, the components x , y , and z of its unit direction vector $\mathbf{s}$ relative to a coordinate system with the source normal as z axis can be chosen by

$$z = \sqrt[n+1]{\mu}, \quad x = \sqrt{1 - z^2} \cos(2\pi\nu), \quad y = x \tan(2\pi\nu) \quad (2)$$

where n is the mode number of the generalized Lambertian radiation lobe, which specifies the directionality of the source. Convert the components of $\mathbf{s}$ into the absolute coordinate of the room. Then P_{los} , the line-of-sight (LOS) power contribution from the source to the receiver, can be calculated.

In the normal Monte Carlo raytracing algorithm, when a ray strikes an opaque surface, the intersection point is treated as a new point source. Thus a new random ray is generated, and the process continues until the ray reaches the receiver. However, the probability of the event that the random ray reaching the receiver before the maximum simulation time is very low, usually less than 10^{-6} . To improve the convergence, we sum P_r , the power directly contributed from each intersection point to the receiver. Substituting the corresponding surface reflection parameters approximated by Phong's model into Eq. (1), we can get the radiation intensity I and further achieve P_r :

$$P_r = I \cdot \Delta\Omega \cdot K \quad (3)$$

where $\Delta\Omega$ is the solid angle subtended by the receiver, and $K = 1$ when the new source is inside the FOV of the re-

The simulated impulse responses due to a 1-W source for configurations D and D' are shown in Fig. 2, where the

In this letter, the split Monte Carlo method based on Phong's model to calculate the impulse response of a wireless indoor IR communications system is presented. It allows evaluation of not only Lambertian diffuse but also DD reflections. The simulation results show the important impact of the DD reflector. This approach can be used to validate previous simulation schemes with less computer complexity and offers increased flexibility for a complex channel with various reflecting patterns.

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