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A novel all-frequency spherical harmonic lighting technique for 5G networks☆

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ABSTRACT

Next generation mobile network has the capacity to realize virtual reality because it can provide low latency, high data rate and low error rate. In virtual reality, instant rendering needs more computing power, but 5G terminal device computing power is relatively weak. Illumination precomputed technology, such as Spherical Harmonic Lighting, provides a mean for rendering scene with limited computing power. For the restrictions on efficiency and storage, Spherical Harmonic Lighting is preferred to capture low-frequency illumination information but missing on high-frequency illumination information. The precomputed illumination dataset will expand rapidly if more high-frequency information is preserved, which prevents its transmission on 5G network. In this paper, we have proposed a method based on wavelet decomposition, that can improve Spherical Harmonic Lighting sampling efficiency and capture more frequency illumination information with adaptive Spherical Harmonic band index. This method can preserve more frequency illumination with relatively small precomputed dataset..

1. Introduction

Next generation mobile 5G network [1,2] provides powerful data transmission, but the computational power of the 5G terminal device is poor. In virtual reality system, instant rendering scene with global illumination remains a major challenge in computer graphics. The difficulty lies in synthesizing realistic image in real-time with limited computing power. Instant rendering technology [2,3] is ideal for virtual reality, but its computing is costly and not suitable for 5G terminal device. The most common instant rendering technologies use the GPU device for acceleration, but for 5G terminal devices, these devices compute power is relative weak and without the acceleration device. The precomputed radiance transfer (PRT) algorithm [4], such as Spherical Harmonic (SH) Lighting [5], provides a method to preserve illumination information in advance and reconstruct it quickly in rendering phase. Thus it can be used in 5G network terminal device with limited computing power. Similarly with 1D or 2D signal FFT decomposition, spherical harmonic decomposition is an orthogonal decomposition of the incident light around the unit sphere. Sampling theorem shows that sampling frequency is at least two times the frequency of the sampled signals, the signals can be restored without distortion. The 3D spherical harmonic decomposition has similar property. The experiments in this paper demonstrate that under-sampling would produce noise and color distortion [6], but higher frequency illumination preservation requires more samples, it is disadvantage for real-time performance. On the other hand, the more illumination frequency needs be preserved, the more

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orthogonal decomposition coefficients are required. Unfortunately, the amount of spherical harmonic coefficients is the square of spherical harmonic band index, for example four spherical harmonic band indexes needs sixteen spherical harmonic coefficients, and sixteen spherical harmonic band indexes sharply needs 256 spherical harmonic coefficients and so on, which is unacceptable for both real-time performance and huge storage requirement. So previous PRT methods are applied only in low-frequency illumination environments, or suffer from the unwieldy size of PRT datasets even after compression.

This paper present a novel method to capture high-frequency illumination based on prior probability which is calculated out by wavelet decomposition. The essence of this method is to make use of the wavelet decomposition to generate illumination prior probability which marks the frequency illumination information, and using more SH coefficients at high-frequency regions and less SH coefficients at low-frequency regions. Additionally, the prior probability can reduce the sample amount, which is benefit to the sampling efficiency.

Briefly, this paper makes the following contributions:

- Generating the environment illumination frequency probability density distribution map by wavelet decomposition and this frequency probability distribution map is help for producing more effective sampling points.
- Adopting adaptive SH coefficients to save illumination information for very rendering vertex, which is benefit to reduce the SH dataset size.

The rest of the paper is organized as follows: section II reviews the related works. In section III, the algorithm and the related theory are presented. Section IV discusses about generation of environment map frequency prior probability. In section V, the results and discussions are presented. The conclusion and future work is discussed in section VI.

2. Related work

Sloan et al. [7,8] propose the low-frequency PRT method to project the light transfer function into the spherical harmonics basis and store those coefficients for restoring illumination information at rendering phase. For governance spherical harmonics (SH) basis coefficients explosion, the principal component analysis (PCA) is exploited for wiping off the coherence. Even though sophisticated compression methods such as non-linear wavelet approximation [9,10] and BRDF factorization [11] are applied, those compression methods are found to be inadequate. Based on the SH basis, the compressed data are still cumbersome for real-time.

Green et al. [12] modeled light transfer function for static scenes, the Gaussian function is used for direct and indirect glossy light non-linear optimization. But this method does not suit for model specular light effects and is uncertain with other all-frequency effects.

Sloan et al. [13] adopted Zonal Harmonics (ZH) to model light transfer functions using non-linear optimizations. ZH transfer function is simple and efficient and yield a more compact representation than the SH basis, but it's still restricted to low-frequency signals and lighting environment.

Similar to PCA [14,15], Singular Value Decomposition (SVD) is another popular method to reduce dimension to analyze and compress data. The high-dimensional space sample data is expressed by another low-dimensional sub-space with only a few principal components.

Tensor approximation is more effective than traditional PCA methods [16,17]. Wang et al. [18] proposed an out-of-core and block-wise technique based on the optimal N-mode SVD algorithm. But even applying the optimal tensor decomposition, the reduced ranks of each mode is still high for efficient reconstruction on GPUs.

In this paper the proposed method captures illumination information based on prior probability, which was estimated from environment maps that differs entirely from simple datasets compression algorithm discussed previously. The prior probability of the light frequency can reduce the sampling quantity and compress the data more effectively.

Environment map sampling method generates samples according to its energy distribution. Environment map can be transformed into finite basis functions, such as wavelets, spherical harmonics and steerable functions. Ostromoukhov et al. [19] resampled the environment map by placing pre-integrated directional lights at the brightest locations. Ramamoorthi et al. [20] used spherical harmonics to directly filter the environment map according to the BRDF. Coombe et al. [21] uses wavelets to generate the sample points.

Bidirectional sampling methods [22] generate samples according to the distribution of BRDF and environment map. Since it is used in both the information of BRDF and the environment map, it can render better quality. Firstly it creates samples according to either the BRDF or the environment map respectively; secondly adjusting those samples according to joint probability distribution, finally, the adjusted samples are used for visibility testing. David Burke et al. [22] proposed two solutions to realize bidirectional sampling: one based on rejection sampling and the other based on the sampling-importance resampling (SIR).

3. Algorithm

Illuminating at point x with view direction w_o is evaluated by an integral over the hemisphere H. The render equation [23,24] is shown as follow:

$$L(x, w_o) = \int_H f_r(x, w_i, w_o) L_i(x', w_i) G(w_i, n) dw_i \quad (1)$$