[Poster] Turbidity-based Aerial Perspective Rendering for Mixed Reality

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ABSTRACT

In outdoor Mixed Reality (MR), objects distant from the observer suffer from an effect called aerial perspective that fades the color of the objects and blends it to the environmental light color. The aerial perspective can be modeled using a physics-based approach; however, handling the changing and unpredictable environmental illumination is demanding. We present a turbidity-based method for rendering a virtual object with aerial perspective effect in a MR application. The proposed method first estimates the turbidity by matching luminance distributions of sky models and a captured omnidirectional sky image. Then the obtained turbidity is used to render the virtual object with aerial perspective.

Keywords: Photorealistic rendering; MR/AR for art, cultural heritage, or education and training.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.3.7 [Computer graphics]: Three-dimensional Graphics and Realism—Color, shading, shadowing, and texture

1 INTRODUCTION

Outdoor MR consists of integrating virtual object into real scenes in a way that the object's appearance corresponds to the real scene's look. When the target object viewed by the observer is far, the perceived object's appearance loses contrast and becomes blurred. This natural effect is known as *aerial perspective* and is due to the light scattered by particles in the atmosphere. Therefore, in such MR applications, we need to render an artificial aerial perspective over the virtual object to emulate the natural atmospheric effect. However, handling with the changing and unpredictable natural atmospheric phenomena such as the environmental illumination and weather conditions, while implementing a fast rendering algorithm, is still challenging.

Representative works related to aerial perspective modelling and rendering are available in the literature. McCartney [1] presented an excellent review that contains relevant data about the scattering phenomena under different weather conditions categorized by the heuristic parameter *turbidity* (T). T relates the scattering by molecules of air and particles of haze and provides a classification of atmospheric conditions, such as T=2 for a clear atmosphere, T=7 for a hazy atmosphere, or T>20 for foggy conditions. Preetham *et al*. [2] proposed a turbidity-based analytical sky model for various atmospheric conditions and used it to render aerial perspective in Virtual Reality (VR) applications. Dobayashi *et al*. [3] proposed a fast rendering approach to generate atmospheric scattering effects using graphics hardware in complete-virtual applications. Nielsen [4] presented a real time rendering system for simulating atmospheric scattering effects for VR. Narasimhan and Nayar [5] proposed a physics-based scattering model to describe the appearances of real scenes under uniform bad weather conditions. Riley *et al*. [6] presented a lighting model for rendering various optical phenomena in virtual applications. Schafhitzel *et al*. [7] rendered planets with atmospheric scattering effects in real time. Bruneton and Neyret [8] presented a real-time method for rendering both sky and aerial perspective from all viewpoints (ground to outer space) in VR.

In order to achieve photometric consistency in MR, modeling the scattering phenomena and achieving real-time rendering are required. In this work, turbidity is estimated from omnidirectional sky images and used in an improved full-spectrum aerial perspective model to render compelling appearances for MR.

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2 ATMOSPHERIC TURBIDITY ESTIMATION

Turbidity is estimated by matching the luminance distribution of turbidity-based Preetham sky models and an omnidirectional sky image captured by a fish-eye lens. First, the sun position at the captured sky image is estimated by either finding the center of the saturated area of the sun or using the longitude, latitude, date and time at the observer's position. Then we calculate the luminance (Y from the XYZ color space) ratio Y_i/Y_{ref} between a sampling point and a reference point in the captured image, and we compute the ratio $Y_i(T)/Y_{ref}(T)$ at the corresponding points in Preetham sky models with the same sun position. The turbidity-based sky model that best matches the captured sky image is the one where the difference between both ratios, that is the ratio error Err, is zero. Hence, we estimate the turbidity by minimizing the following equation at N sampling points using the Levenberg-Marquardt algorithm (LMA):

$$\underset{T\in[1,20]}{\arg\min} \sum_{i=1}^{N} \left| \frac{Y_i(T)}{Y_{ref}(T)} - \frac{\mathrm{Y}_i}{\mathrm{Y}_{ref}} \right|. \tag{1}$$

Since the Preetham sky model does not provide equations for calculating the brightness of cloudy pixels, the Random Sample Consensus (RANSAC) approach is used to remove cloudy pixels (outliers) from the sampling and estimate turbidity only from clear-sky pixels (inliers).

3 AERIAL PERSPECTIVE RENDERING

The intensity value I_c for channel $c \in \{r,g,b\}$ recorded by a camera provides the colour based-rendering equation that integrates the spectral light going through the camera lens and the camera's spectral sensitivity q_c over the visible spectrum (380 to 780nm). In outdoor scenes, the total light perceived by the camera (observer) can be modelled as a summation of a direct transmission and an airlight. We approximated the spectral sensitivity by a Dirac's delta function to obtain the intensity value I_c of a virtual object's pixel perceived by an observer at distance s as

$$I_c(s) = I_{0,c} \cdot \Gamma_c(T,s) + I_{\infty,c}(T,\theta)(1-\Gamma_c(T,s)) , \tag{2}$$

where $I_{0,c}$ is the intensity value of a pixel at the surface of the virtual object, and Γ_c is the approximate attenuation factor:

$$\Gamma_c(T,s) = \frac{\int_{380\text{nm}}^{780\text{nm}} e^{-\beta_{sc}(\lambda,T,h_0)s} q_c(\lambda) d\lambda}{\int_{380\text{nm}}^{780\text{nm}} q_c(\lambda) d\lambda}. \quad (3)$$

We benefit from q_c estimated in [9]. $I_{\infty,c}$ is the intensity value of a pixel at an infinite distance in the viewing direction with zenith angle θ. We approximated $I_{\infty,c}$ at any viewing direction using [2]:

$$I_{\infty,c}^{a} = I_{\infty,c}^{b} \left[\frac{1+(0.1787T-1.4630)e^{(-0.3554\,T+0.4275)/\cos\theta_a}}{1+(0.1787T-1.4630)e^{(-0.3554\,T+0.4275)/\cos\theta_b}} \right], \quad (4)$$

where the upper indexes "*a*" and "*b*" stand for the pixel at the target object and the pixel at the visible sky portion respectively that share the same azimuth.

4 Proposed Improved Scattering Model for MR

The total scattering coefficient β_{sc} is a summation of the Rayleigh and Mie scattering coefficients, β_R and β_M respectively. We propose an improved scattering model that ensures a compelling result when implementing the aerial perspective for MR. For this purpose, we employed real measurements of [1] and adapted a turbidity-based classification of the scattering coefficients by considering T=1.6 as the turbidity for an exceptionally clear atmospheric condition, and linearly fitting β_R and β_M to [1].

Our modified Rayleigh scattering coefficient is given by

$$\beta_R = \frac{8\pi^3(n^2-1)^2}{3N\lambda^4}\left(\frac{6+3p_n}{6-7p_n}\right) K_R \times e^{\frac{-h_0}{H_0}}, \quad (5)$$

where λ is wavelength, n, p_n, H_0, and N are same as in [10] and h_0 is the height at the observer. We calculated a straightforward multiplicative correction factor K_R =1.0396 based on [1].

Our modified Mie scattering coefficient is given by

$$\beta_M = 0.434c(T)\pi\left(\frac{2\pi}{\lambda}\right)^{v-2} K_M \times e^{\frac{-h_0}{H_0}}, \quad (6)$$

where υ and H_0 are same as in [11]. Using [1], we propose a concentration factor $c(T)=(0.65T-0.65)\times10^{-16}$ that guarantees a non-scattering case for T=1 and a corrected Fudge factor K_M=0.0092 adapted to MR.

5 Experimental Results

All the experiments were implemented in C++ with a PC (OS: Windows 7; CPU: Corei7 2.93GHz; RAM: 16GB). We used the Virtual Asukakyo project [12] that employs MR technology to restore the ancient capital of Japan. We rendered the CG model of Asukadera, an ancient temple in Asukakyo, on a fixed view in the current Tokyo city. The height at the observer position was h_0=40m. The distance from the rendered Asukadera to the observer was about 3500m. Turbidity was estimated from sky images captured by Canon EOS5D with a fish eye lens. Figure 1 shows our results with rendering speed of 1800 pixels/sec.

6 Conclusion

We proposed an efficient turbidity-based method for rendering virtual objects with aerial perspective effect in MR. Our method estimates turbidity by matching the luminance distributions of a sky model and an omnidirectional captured sky image. We have also proposed an improved turbidity-based scattering model for MR. Our model benefits from [1] to classify scattering coefficient values via turbidity. We use this enhanced scattering model to provide a full-spectrum aerial perspective rendering model. Our rendering approach benefits from [6] to go from radiance light to RGB colors. Although our rendered results applied to VA did not reach real time, this can be easily accelerated in the future via GPU implementation. Besides, the fixed view issue can be handled using conventional tracking systems.

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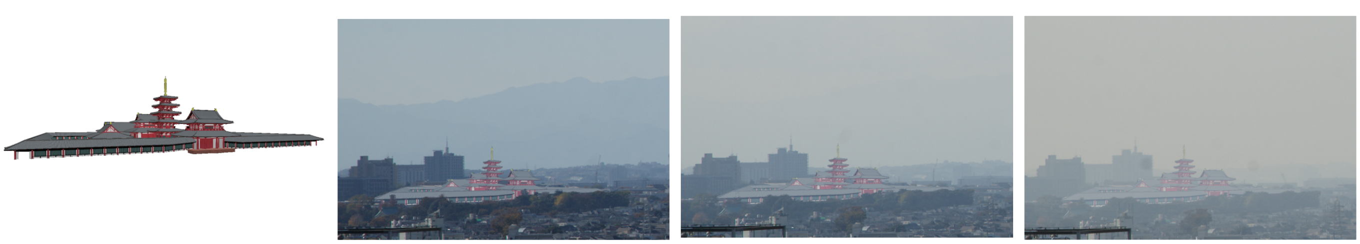

Figure 1. Rendering results. From left to right. Virtual Asukadera model without aerial perspective effect. Results of Virtual Asukadera rendered with our aerial perspective effect for T=2.10. Rendering result for T=2.94. Rendering result for T=4.36.