AN ANALYTICAL APPROACH FOR SIMULATING AERIAL PERSPECTIVE EFFECTS ON DISTANT OBJECTS

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To

my wife, hamimahujir
&
my mom, juliadolhassan

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ABSTRACT

Aerial perspective effects are an integral part of a virtual application for outdoor simulation. These effects are modelled using the light transfer equation; borrowed from the field of physics. Typically, these applications make do with a watered-down version of the equation since the physically correct version requires heavy nested loops and complex optical depth estimation. The normal practice is to assume the atmosphere's density as constant to allow the usage of distance between points as optical depth. However, this move causes failure in capturing the darkening effect of sky area approaching zenith, due to density fluctuations as the altitude increases. An analytical-based approach is proposed here to solve the above problem. A look-up table containing five-parameter coefficients of a chosen parametric luminance function was prepared in advance as a function of altitude, turbidity and Sun position. During the real-time visualization, a single rendering equation is used to determine each vertex's display colour. Adding the initial colour value of the current vertex to its atmosphere-contributed colour value solves the equation. The atmosphere-contributed colour is obtained by an exponential interpolation of five separate colour values. Each value represents the colour of the intersected sky patch at each reference layer. The intersected sky patch is found by finding which sky patch coordinate solves the vector equation of a line passing through the camera's point and the current vertex's point. By referring to the look-up table, these five colour values are computed using the chosen parametric luminance function. This approach was implemented using the Cg Language as a vertex shader. Test results have shown that the proposed approach is able to produce visually correct daylight sky colour distributions at any altitude within the 30km range.

ABSTRAK

Kesan perspektif udara merupakan komponen utama bagi sesebuah aplikasi maya untuk simulasi persekitaran luar. Kesan-kesan ini dimodelkan dengan persamaan pemindahan cahaya yang dipinjam dari bidang fizik. Kebiasaannya, aplikasi-aplikasi sebegini hanya mengimplementasikan versi ringkas persamaan tersebut memandangkan versi asal dibebani oleh gegelung bersarang pelbagai lapisan serta pengiraan kedalaman optik yang rumit. Lazimnya, ketumpatan udara dianggap malar supaya parameter kedalaman optik boleh diganti dengan nilai jarak di antara dua titik. Walau bagaimanapun, langkah ini menyebabkan tiada kesan penggelapan di kawasan langit yang menghampiri zenit, berpunca dari perubahan aras ketumpatan udara semasa kenaikan paras altitud. Satu pendekatan berasaskan analitikal dicadangkan sebagai langkah penyelesaian untuk permasalahan tersebut. Sebuah jadual rujukan yang mengandungi nilai lima parameter bagi satu persamaan luminans berparameter terpilih disediakan lebih awal. Ianya dirujuk berdasarkan nilai altitud, aras kekeruhan langit serta posisi matahari. Semasa visualisasi masa nyata, satu persamaan tunggal digunakan untuk mengira warna paparan bagi setiap vertek. Persamaan ini diselesaikan menerusi operasi penambahan nilai warna asal vertek semasa dengan nilai warna sumbangan atmosfera. Nilai warna sumbangan atmosfera dikira dengan rumus interpolasi secara eksponen terhadap lima nilai warna berbeza. Setiap nilai mewakili warna bagi petak langit bersilang di setiap lapisan rujukan. Petak langit bersilang diperolehi dengan mencari koordinat petak langit yang berjaya menyelesaikan persamaan vektor untuk garisan yang melalui titik kamera dan titik vertek semasa. Kelima-lima nilai warna tadi dikira menerusi persamaan luminans berparameter terpilih dengan merujuk kepada jadual rujukan. Dengan menggunakan bahasa pengaturcaraan Cg, pendekatan ini diimplementasi sebagai aturcara pembayang vertek. Hasil-hasil ujian membuktikan keupayaan pendekatan ini dalam menghasilkan kepelbagaian taburan warna langit di waktu siang yang tepat dari segi visual, sehingga paras altitud 30km.

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ABBREVIATION		DESCRIPTION
2D	-	Two-dimensional
3D	-	Three-dimensional
ABCDE	-	Perez et al's (1993) five-parameter coefficients
APACC	-	Analytical parametric atmosphere-contributed colour
BRDF	-	Bidirectional reflectance distribution function
CIE	-	International Commission of Illumination
COESA	-	Committee on Extension to the Standard Atmosphere
CPU	-	Central processing unit
CRT	-	Cathode ray tube
fps	-	Frames per second
GPU	-	Graphical processing unit
HDR	-	High Dynamic Range
IDMP	-	International Daylight Measurement Program
LTE	-	Light transfer equation
RGB	-	Additive colour (red, green and blue)
SMARTS2	-	Simple Model for the Atmospheric Radiative Transfer of Sunshine
SPCTRL2	-	Simple Solar Spectral Model for Direct and Diffuse Irradiance on Horizontal and Tilted Planes at the Earth's Surface for Cloudless Atmospheres
SPD	-	Spectral power distribution
XYZ	-	A set of tristimulus values (X, Y and Z), derived from the CIE 1931 colour matching experiment
Yxy	-	Luminance Y, chromaticity x and chromaticity y

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The task of rendering an object seen through the Earth's atmosphere is of far greater importance nowadays, due to the surge of interest in using interactive virtual landscape in areas such as computer gaming, military, tourism et cetera (VTP, 2005). An object's rendered colour is what gives it a sense of scale and distance. Flight simulator is an example of such application; enabling the pilot to traverse the vast virtual sky without any constraints.

Figure 1.1 Aerial perspective effects in action (Nielsen, 2003). Notice the darkening of sky area closer to zenith as the altitude increases.

This altitude-flexible navigation requires the parameter ensuing effects towards the daylight sky colour to be captured correctly; a feature typically missing from the current batch of aerial perspective rendering methods (Nielsen, 2003). In addition, the increasing contents and details of such virtual landscape in today applications require the aerial perspective rendering problem to have a lesser priority in the system resources allotment (Nielsen, 2003). Present methods were based on a taxing real-time solving of the light transfer equation (LTE), thus forced to employ an inferior light attenuation model and restricts the light attenuation calculation at trichromatic wavelengths only. Subsequently, the colour precision of the final rendered scene will askew slightly.

Johnson and Fairchild reported in their findings (1999) that the usage of a trichromatic value instead of a full-spectral representation of colour causes large colour shifts. The light attenuation processes, namely: i) in-scattering, ii) out-scattering and iii) absorption are important phases as they solely determine the arriving spectral colour at the end of the viewing path. To lose valuable colour information here is simply disastrous. Minnaert, in his famous book on the light physics through the Earth's atmosphere (1954), noted that ozone absorption is the key reason why the zenith sky remains blue during low Sun altitudes. Present aerial perspective rendering methods (Hoffman and Preetham, 2002; Nielsen, 2003) excluded absorption from their light attenuation model. They justified the exclusion based on the claim by Haltrin (1996) which states that the absorption of the visible light is negligible except for the ozone layer. For this reason, layers below the ozone layer can be treated as a full scattering-only medium. The exclusion is not entirely surprising since these works are more ontogenetic-based than teleological; the two polar extremes on modelling approach (Barr, 1991).

1.2 Research Background

In the past, real-time rendering of outdoor scenes has primarily dealt with the problem of increasing the geometric detail of visible terrain (Nielsen, 2003). The problem of sky dome visualization and aerial perspective rendering usually took the backseat. Rudimentary methods such as texture mapping and vertex colour interpolation scheme were commonly used to provide the impression of the daylight sky. Meanwhile, aerial perspective effects on distant objects were faked using simple range-based fog.

Scientific improvements were then made, as witnessed in works on analytical sky luminance model (Moon and Spencer, 1942; Kittler, 1967; Perez et al, 1993; Preetham et al, 1999). These models were based on fits of actual data except for Preetham et al's (1999), which employed simulated data. Examples of such actual sky luminance measurement are (LBL, 1986; Lam, 1996; Lau, 1999). These measurements were taken at a unique site for at least a year. The scarcity of such mature actual data forced researchers to use synthetic data instead. Existing solar spectral models such as SMARTS2 (Gueymard, 1995) and SPCTRL2 (Bird and Riordan, 1986) are able to approximate a sky radiance/luminance/colour distribution map on a given set of inputs. Nevertheless, the existing framework design of a sky luminance model can only provide the sky dome's colour (viewing paths with infinite length); not for a viewing path that is intersected by an object.

Early aerial perspective rendering methods such as Hoffman and Preetham (2002), and Dobashi et al (2002) overcame the above shortcoming of sky luminance models. Since the daylight sky colour distribution and aerial perspective effects on distant objects are both caused by the exact same process: the travelling light interactions with the Earth's atmosphere, the two phenomenons can therefore be simulated using a single equation as a function of the optical depth. The above methods were based on the numerical solution of the light transfer equation (LTE); a term discussed thoroughly in Sloup (2002). Since the LTE is evaluated in real-time for an arbitrary viewing path, any variations on its: i) optical depth and ii) angular angle from the Sun will be reflected back into its spectral colour result. This feature is unavailable in a sky luminance model whereas the two attributes are fixed. Conversion issues of spectra to a displayable value unit are govern by the International Commission of Illumination, abbreviated from its French title: *Commission Internationale de l'Eclairage*, (CIE). See Poynton (1995) for further reading on this matter.

All of the above methods, bar Nielsen's (2003), hold an incorrect assumption that the Earth's atmosphere density is constant. A daylight sky dome colour distribution is the same regardless of the observer's current altitude. This assumption would not provide a realistic result in a flight simulator application, in which the observer's altitude has a significant role to play. Nielsen (2003) extended Hoffman and Preetham's (2002) model to consider the increasing altitude effect towards the daylight sky colour distribution, yet his solution is far from physically-correct. Various crude simplifications were implemented in Nielsen's (2003) model, in order to maintain the interactive frame rates.

1.3 Current Issues

1.3.1 Speed vs. Physical Accuracy

Present aerial perspective rendering methods were burdened by the weight of the real-time solving of the LTE. This trade-off between speed and physical-accuracy always results to the reduction of the latter. As mentioned before, these methods were forced: i) to restrict the light attenuation calculation at trichromatic wavelengths (RGB) and ii) to use an inferior light attenuation model. These simplifications were made to maintain the interactive frame rates at an acceptable level. Musgrave (1993) discussed this dilemma in detail in his thesis. He stressed that the priority must be given to speed due to the application of the developed model in a real-time domain. Applications such as a flight simulator need only to convince user of the simulated scene's visual realism; regardless of the method used in achieving it.

1.3.2 Solving the Out-of-Gamut Colour Problem

Tone mapping is a computer graphics technique used to approximate the appearance of high dynamic range images in media with a more limited dynamic range. Essentially, tone mapping addresses the problem of strong contrast reduction from the scene radiance values to the displayable range while preserving the image details and color appearance important to appreciate the original scene content. This problem, termed as an out-of-gamut colour, typically arisen after conversion between colour spaces. Examples of tone mapping techniques are (Fattal et al, 2002) and (Mantiuk et al, 2005).

An interesting approach to tone mapping of High Dynamic Range (HDR) images is inspired by a theory proposed by Gilchrist et al (1999). Their theory comprehensively explains many characteristics of the human visual system such as lightness constancy and its spectacular failures, which are important in the perception of images. The key concept of this tone mapping method (Krawczyk et al, 2005) is a decomposition of an HDR image into frameworks of consistent illumination and the local calculation of the lightness values. The net lightness of an image is calculated by merging of the frameworks proportionally to their strength. Particularly important is the anchoring: relating the luminance values to a known brightness value, namely estimating which luminance value is perceived as white in the scene. This approach to tone mapping does not affect the local contrast and preserves the natural colors of an HDR image due to the linear handling of luminance. Researchers are now actively pursuing techniques to transfer High Dynamic Range (HDR) imagery to real-time applications (Durand and Dorsey, 2000; Goodnight et al, 2003).

1.3.3 Transferring the Computational Burden to GPU

Recent works have begun investigating the use of modern shader technology for simulating atmospheric scattering effects (Dobashi et al, 2002; Hoffman and Preetham, 2002). A shader is a computer program used in 3D computer graphics to determine the final surface properties of an object or image. This often includes arbitrarily complex descriptions of light absorption, diffusion, texture mapping, reflection, refraction, shadowing, surface displacement and post-processing effects.

By design, shaders are ideal candidates for parallel execution by multiple graphic processors, which are usually located on a video card, allowing for scalable multiprocessing and lessening the burden on the CPU for rendering scenes.

There are two different applications of shaders in real-time shading languages: i) vertex shader and ii) pixel shader. Vertex shaders are applied for each vertex and run on a programmable vertex processor. Pixel shaders are used to compute properties which, most of the time, are recognized as pixel colors. Pixel shaders are applied for each pixel as opposed to each vertex. They are run on a pixel processor, which usually features much more processing power than its vertex-oriented counterpart.

1.4 Problem Statement

The first problem faced by the previous works in this area is the missing darkening effect on sky area closer to zenith as the altitude increases. Analytical sky luminance models such as (Moon and Spencer, 1942; Kittler, 1967; Perez et al, 1993; Preetham et al, 1999) were all fitted from the daylight sky luminance distribution data measured/simulated at ground level. As the result, these models are unable to simulate the above effect at all. Aerial perspective rendering methods such as (Hoffman and Preetham, 2002; Dobashi et al, 2002) assumed that the observer is always positioned on the ground. They do not simulate the changes in colour and intensity that appear as the altitude increases rapidly. This allows them to use the distance between two points (observer and object) directly as the optical depth. This shortcut would not work in a flight simulator application, as the optical depth depends on both the viewing path's length and the average density of the penetrated atmosphere. As expected, this shortcut will also create problem latter when dealing with terrain that contains significant differences in height. One immediate solution that springs to mind is to use an analytical sky luminance model. Since the all-sky luminance distribution maps are prepared *offline* before being fitted to a single parametric equation, the process of obtaining them can therefore be as precise as can be. Retrieving these luminance values will only require minimal computational cost.

Sky luminance distribution at any altitude can theoretically be simulated using any of the existing solar spectral models. This statement holds true if the required atmospheric parameters at that particular layer of the atmosphere are available. However, as being mentioned earlier, a sky luminance model can only provide the sky dome's colour. There is no built-in mechanism for rendering aerial perspective effects on distant objects. This conundrum presents the second problem that needs to be solved here.

1.5 Goal

The main goal of this research is to develop an improvised single aerial perspective rendering algorithm. Rather than recalculating the LTE of all of the viewing paths each time the scene is updated, the algorithm uses an analytical model instead. The algorithm must be able to render both daylight sky and distant objects, as seen through the Earth's atmosphere from varying altitudes.

1.6 Research Objectives

(i) To construct a general Earth's atmospheric profile up to 30km; where it will be use together with a chosen solar spectral model to generate the all-sky colour distribution maps at each reference altitudes.

(ii) To develop an analytical parametric atmosphere-colour contribution (APACC) model based on fits of the earlier simulated maps.

(iii) To integrate the APACC model in a single aerial perspective rendering equation. This is done by developing necessary algorithms that will facilitate the improvised algorithm in rendering aerial perspective effects on distant objects.

1.7 Research Scopes

(i) The term "*general Earth's atmosphere*" is used here to represent a generic atmospheric profile that did not represent any specific site on Earth. The atmospheric constituents' measurements used during the profiling task were obtained from various sites that differ geographically; selected merely on availability basis.

(ii) The proposed method is only concerned on simulating the aerial perspective effects on both sky dome and distant objects under a clear (zero cloud presence) daylight (from sunrise to sunset) sky.

(iii) Other atmospheric effects such as rainbows, mirages, halos et cetera are not simulated.

(iv) The actual Sun will not be rendered onto the scene.

(v) A *stripped-down* version of a flight-simulator application, without the unnecessary *bells and whistles*, was built as the test bed.

(vi) In the prototype application, i) a 2D orthographic sky dome is used instead of a 3D hemispherical version, ii) no actual terrain will be rendered as distant objects are represented by two 3D boxes, iii) the Sun position and turbidity are preset before each demo run, iv) the camera (observer) can only moves on its y-axis (altitude), and v) transparency is replicated by positioning the two boxes at different distances from the camera.

1.8 Research Contributions

This research contributes to the following aspects:

(i) By using an analytical model to replace the traditional real-time solving of the light transfer equation, the cost of determining the arriving spectral colour at the end of each arbitrary viewing path in the rendered scene is reduced significantly.

(ii) By treating the Earth's atmosphere density as an exponential function of altitude, the sky colour distribution effects exhibited when observed at high altitudes can be captured correctly.

(iii) By packaging the proposed method in a single rendering equation form, it can easily be implemented in a modern real-time graphical rendering pipeline, either as a vertex or pixel shader, thus unloading a huge amount of workloads from the CPU to the GPU.

This work is considered as an applied research, hence benefiting the following areas:

(i) Computer games – A computationally-efficient method will enable low-end computers to render the aerial perspective effects at an acceptable interactive frame rates. Flight simulator game reaps the most benefits.

(ii) Military/airline industry – Help familiarize beginner pilot with the various daylight sky conditions (turbidity level and time setting) as expected to be observed in the real world. Aerial perspective effects assist pilot to judge both scale and distance properly.

(iii) Tourism – Virtual tourism via the "*fly-through*" method.

1.9 Organization of Thesis

This thesis contains six chapters as follows:

Chapter 1 briefly introduces the topic of aerial perspective effects computer modelling and its related research backgrounds. The problem statements are defined next. Goal, objectives and scopes of research are then stated clearly and concisely. Research contributions are also listed and elaborated.

Chapter 2 conducts a literature review on all three given research objectives. This chapter covers the topic of: i) atmospheric profiling and the preparation of the all-sky colour distribution maps, ii) analytical luminance models, and iii) real-time aerial perspective rendering methods.

Chapter 3 presents the research methodology. Every algorithm that were used to accomplish the research objectives are presented and justified here.

Chapter 4 reports on the implementation of the proposed methodology. The methodology is designed to be implemented modularly by two phases: i) pre-processing (*offline*) and ii) run-time processing (real-time). This chapter illustrates the workflow of these modules using relevant pseudo codes and diagrams.

Chapter 5 shows the research results and their individual analysis. Properties of the proposed method are then highlighted by comparing them with previous methods' results.

Chapter 6 summarizes and concludes this study. It also outlines the topics for future work.