Modeling and Rendering Methods of Clouds

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Abstract

Recently, simulation of natural phenomena, such as water, smokes, fire, clouds, have been attempted in computer graphics. Clouds play an important role when generating images of outdoor scenes, the earth viewed from outer space and the visualization of weather information.

This paper describes the modeling methods of clouds, and an efficient calculation method for light scattering due to clouds taking into account both multiple scattering and sky light. The methods discussed here are also useful for displaying snow.

Keywords: Clouds, multiple scattering, satelight image, metaballs, Fractal, natural phenomena, cellular automaton

1. INTRODUCTION

Display of natural scenes such as mountains, trees, the earth, the sea, and the waves have been attempted. This paper discusses the modeling and shading methods of clouds. The display of clouds is indispensable for the background images of buildings and flight simulators.

For displaying natural phenomena such as clouds, we have three important factors; 1) modeling: controlling its shape (Fractal surfaces) and density distribution. 2) shading (optical effects): light absorption/scattering due to cloud particles illuminated by the sun and the sky light. The color of clouds varies according to the relationship between the viewing direction and the position of the sun. It is well known that for clouds with such a high albedo multiple scattering can not be ignored. 3) dynamics (animation): growth of clouds and typhoons.

For displaying clouds, mapping of fractal textures onto ellipsoids is often used. We discuss here more realistic 3D clouds. Moreover, this paper also discusses an animation method for clouds generated by a sequence of satellite images or an animation method using cellular automation.

2. MODELING OF CLOUDS

A lot of methods has been developed for modeling clouds and can be classified into two groups. Methods in the first group create clouds by procedural modeling. This includes some techniques, such as fractals (Voss, Musgrave), Fourier synthesis (Gardner), solid texture combining metaballs and a noise function (Ebert), spectral synthesis (Sakas), and interpolating the specified density values (Stam, Fuime).

Methods classified in the second group model by simulating the physical process of the clouds: the numerical simulation of the fluid dynamics (Kajiya), qualitative simulation (Neyret), and dynamic simulation of the particles (Kikuchi).

We have developed the following three types of cloud modeling.

(1) 2D Fracltal clouds[1]

We have modeled clouds to generate realistic images of the earth viewed from space. The density distribution of clouds is expressed by mapping the fractal images of the Mandelbrot set. To take into account clouds with various altitudes, multiple imaginary spheres are employed to map fractal images on them.

(2) 3D Fractal clouds/snow by using metaballs[2][3]

The density distribution of the cloud/snow is defined by using the meta-ball technique. Each metaball is defined by its center, radius, and the density at the center of the ball. The surface of a cloud/snow is defined by the isosurfaces of potential fields defined by the metaballs. First, several metaballs are arranged to form the basic shape of the cloud. Then, small meta-balls on the surface of the cloud are generated recursively by using the following fractal method to form the subtle fringe of the cloud. The isosurface is extracted by the marching-cubes algorithm and triangulated. New balls are then generated within each triangle. Generating new balls produces a new surface, which is again triangulated. And again new balls are generated.

(3) 3D clouds from a satellite image[4]

In recent years, many methods of image-based rendering and/or modeling have been developed. We utilized the approach for modeling large-scale clouds viewed from space such as typhoon. Parameters are determined automatically so that a synthesized image of clouds modeled by metaballs coincides with the satellite image. Together with the satellite image, the proposed method makes use of the fact that the color of clouds can be calculated by integrating the scattered light due to particles in them. Determining parameters of the metaballs is equivalent to solving an inverse problem of determining the density distribution inside the clouds so that the synthesized image is similar to a satellite image.

3. SHADING MODELS FOR CLOUDS

To display realistic images, a precise shading model is required. Clouds are illuminated by both direct sunlight and sky light affected by atmospheric scattering. The calculation of cloud/snow intensities has been assumed to be complex due to strong forward scattering. However, we proposed an efficient calculation method using these scattering characteristics in a positive way. The sky light is a very significant factor when sky light is rather stronger than direct sunlight, such as at sunset/sunrise. The reflected light from the ground also can not be ignored, and we take these effects into account. The color variation of incident light on them passing through the atmosphere and sky light. For the calculation of multiple scattering, the space containing the clouds/snow is subdivided into a number of volume elements. At least the 3rd order of scattering is calculated in our method. The scattered light at the clouds is attenuated by particles in the atmosphere and reaches the viewpoint. Sunlight is absorbed when light passes through the atmosphere.

4. ANIMATION OF CLOUDS

We have developed two animation methods of dynamic clouds.

(1) Clouds are modeled from a sequence of satellite images [4]. Then they are morphed by interpolating the parameters of the metaballs. In our method, the user inputs the flow of the atmosphere as Bezier curves by observing the satellite images. The smooth transitions of clouds are realized by moving metaballs along the curves and changing their densities.

(2) The cellular automaton is used for calculating the density distribution of clouds which varies over time[5]. By using the cellular automaton, the distribution can be obtained with only a small amount of computation since the dynamics of clouds are expressed by several simple transition rules.

5. EXAMPLES AND CONCLUSIONS

Fig.1 shows examples of cumulonimbus. Fig. 2 shows examples of clouds using satellite images viewed from space. For the satellite image, an infrared image of a typhoon taken from the meteorological satellite, “HIMAWARI” is used. Since clouds are modeled in three-dimensional space, they are seen from different viewpoints and shadows can be calculated. Fig.3 in the color page shows various examples of clouds. The clouds in (a) are generated by Mondelbrot set[1]. The clouds/snow in (b) - (d) are generated by metaballs combined with fractal[2][3]. (e) is an image from the animation entitled “Weather Report”, that visualizes weather information[4]. In this animation, the movement of a typhoon passing across Japan is visualized. (f) is one image from the dynamic movement of clouds using the cellular automaton[5]. Even though single scattering is taken into account for (a),(e),(f), multiple scattering is taken account for (b),(c),(d).

Fig.1: Clouds generated by metaballs taking into account multiple scattering.

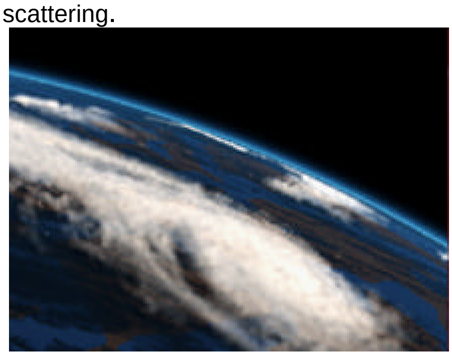

Fig.2: Clouds generated from a satellite image.

We can summarize our rendering methods of clouds as follows: **(1)** The clouds/snow can be modeled by using metaballs. The complicated cloud surfaces are generated by a fractal technique applying to metaballs. **(2)** For anisotropic multiple scattering, the optical paths of the light scattered in the viewing direction are limited because of strong forward scattering. Employing the pattern expressing the contribution ratio at each voxel to the specified voxel in the sample space, the calculation cost for the total space can be reduced. **(3)** By making use of a satellite image of real clouds, the proposed method can generate clouds with authentic shape and color. **(4)** To animate clouds, they are generated from a series of satellite images and shapes of clouds at each frame are obtained by interpolating them.

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