Visual Informatics 1 (2017) 1–8

Contents lists available at ScienceDirect

Visual Informatics

journal homepage: www.elsevier.com/locate/visinf

Visual simulation of clouds

Yoshinori Dobashi [a], Kei Iwasaki [b], Yonghao Yue [c], Tomoyuki Nishita [d,*]

[a] Hokkaido University/UEI Research, Japan
[b] Wakayama University/UEI Research, Japan
[c] The University of Tokyo, Japan
[d] UEI Research/Hiroshima Shudo University, Japan

ARTICLE INFO

Article history:
Available online 27 January 2017

Keywords:
Clouds
Procedural modeling
Image-based modeling
Fluid simulation
Feedback control
Genetic algorithms

ABSTRACT

Clouds play an important role when synthesizing realistic images of outdoor scenes. The realistic display of clouds is therefore one of the important research topics in computer graphics. In order to display realistic clouds, we need methods for modeling, rendering, and animating clouds realistically. It is also important to control the shapes and appearances of clouds to create certain visual effects. In this paper, we explain our efforts and research results to meet such requirements, together with related researches on the visual simulation of clouds.

1. Introduction

Clouds are important elements when synthesizing images of outdoor scenes to enhance realism. Many methods have therefore been continuously proposed for visual simulation of clouds from the very beginning of the history of computer graphics (Blinn, 1982; Max, 1986; Gardner, 1985). These methods are used in many applications such as flight simulators, movies, computer games, and so on.

There are several important factors for creating realistic images of clouds. The first one is the shapes. The shapes of clouds are defined by three-dimensional density distribution of cloud particles, or water droplets. We need a method for synthesizing a realistic distribution of the cloud particles. Once we have the realistic distribution, we need a method that can compute realistic colors of clouds, taking into account attenuation and scattering of light inside the clouds. This requires the simulation of interactions between light and the small particles, which is usually time-consuming. Moreover, when we want to synthesize animation of clouds, we also need a method that can compute complex but fascinating motions of clouds. Finally, efficiency and controllability are also important factors for applications in computer graphics, such as movies and computer games.

There are tremendous numbers of previous work to meet such requirements descried above. In this article, we review some of those previous work and introduce our continuous efforts for modeling, rendering, and animating clouds realistically. Our inverse approach for visual simulation of clouds is also explained.

2. Modeling clouds

In order to display realistic clouds, the density distribution of clouds requires to be defined. Many methods have been developed for this purpose. There are two major approaches to the modeling of clouds: a procedural approach and a physically based approach.

Procedural modeling is the most popular approach to modeling clouds and some kind of noise functions are usually used. Voss used the idea of fractals for modeling clouds (Voss, 1983). Gardner proposed a method using textured ellipsoids for visual simulation of clouds (Gardner, 1985). Ebert et al. developed a method combining metaballs and a noise function (Ebert, 1997). Sakas modeled clouds by using spectral synthesis (Sakas, 1993). Schpok et al. have developed a real-time system for the procedural modeling of clouds (Schpok et al., 2003). A more detailed explanation of the procedural modeling of clouds can be found in Ebert (2003). These methods can generate realistic clouds, but many parameters are required to be specified by trial and error to synthesize realistic clouds.

Clouds can be generated by physically based simulation of the cloud formation process. Kajiya and Herzen solved atmospheric fluid dynamics, numerically, for modeling cumulonimbus clouds (Kajiya and Herzen, 1984). Miyazaki et al. proposed a method for modeling various types of cloud by using the method called a coupled-map lattice, being an extended version of cellular automata (Miyazaki et al., 2001). They also proposed a method for simulating the cloud formation process by improving the method

* Corresponding author.
E-mail address: nishita@shudo-u.ac.jp (T. Nishita).
Peer review under responsibility of Zhejiang University and Zhejiang University Press.

http://dx.doi.org/10.1016/j.visinf.2017.01.001

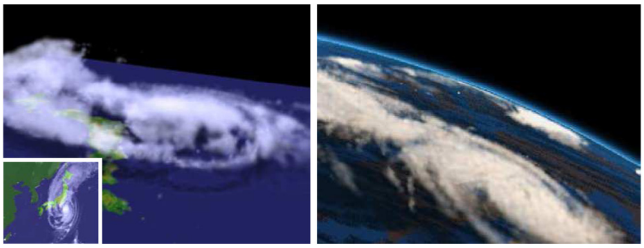

Fig. 1. Modeling of clouds using satellite images. The left image shows a typhoon synthesized by using the inset image. The right image shows a different typhoon viewed from space.

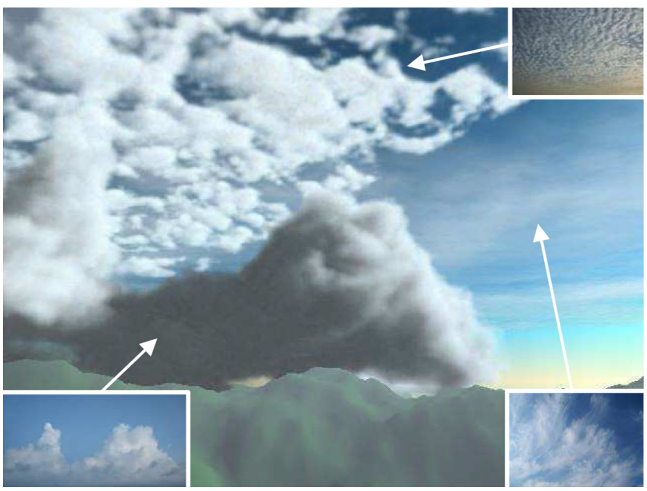

Fig. 2. Modeling of clouds from photographs. Three types of clouds in the synthetic image are modeled from the corresponding photographs shown in the inset images.

proposed by Kajiya and Herzen (1984). By using these methods, realistic clouds can be created and these can also be used for animating clouds (see 4). However, one of the problems with these methods is that the computational cost is very high.

The above problems can be resolved by employing an image-based approach, that is, modeling clouds from photographs of real clouds. Since taking multiple photographs of clouds from different directions is usually difficult, the image-based methods for modeling clouds use a single image as an input (Dobashi et al., 1998, 2010; Yuan et al., 2014). The purpose of these image-based modeling methods is not to reconstruct the exact shapes of clouds in an image but to use it as a guide to generate clouds that look similar to those in the image. We have developed the method for modeling large-scale clouds by using infrared satellite images (Dobashi et al., 1998). We used metaballs to represent the density distributions of clouds and the parameters of metaballs were automatically adjusted so that the resulting synthesized clouds became similar to those in an infrared satellite image. The method can generate realistic images of a typhoon viewed from space, as shown in Fig. 1. The method, however, is not suitable for photographs taken from the ground, where we need to remove the effects of the sunlight illumination and the background sky.

We then developed a method that synthesized clouds from a photograph taken from the ground (Dobashi et al., 2010). This method can generate three types of cloud: cirrus, altocumulus, and cumulus. Examples of the synthetic clouds generated by this method are shown in Fig. 2. The method initially creates an image of the sky by estimating the sky colors behind the clouds in the photograph. Then, the intensity and the opacity of the clouds are calculated by comparing the input photograph with the sky image.

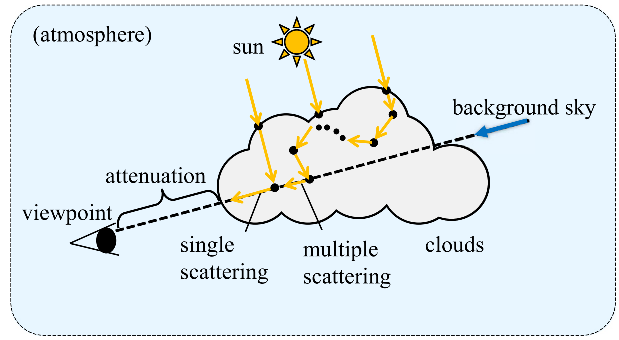

Fig. 3. Important factors that affect the intensity of clouds.

We developed three methods using the intensity and the opacity for generating the three types of cloud, respectively. Cirrus clouds are very thin and self-shadows are seldom observed. Therefore, we modeled cirrus as a two dimensional texture. Altocumulus is also thin, but self-shadows are observed. Therefore, a three-dimensional density distribution must be defined. We used metaballs to define the density distribution and the parameters of the metaballs were determined by using the intensity and opacity information. Finally, for cumulus clouds, the method initially generates a surface shape of the clouds by calculating the thickness at each pixel by using the opacity information. The density inside the shape is then generated, employing a procedural approach. Yuan et al. (2014) also proposed an image-based method for modeling cumulus clouds by improving our method.

3. Rendering clouds

The best way to compute realistic colors of clouds is to simulate optical phenomena that happen inside clouds. Since clouds are collections of small water droplets, scattering and absorption of light due to cloud particles are the most important factors. The atmosphere also affects the appearance of the clouds.

Let us first describe important factors that determine the colors of clouds (see Fig. 3). When the light reaches a point inside clouds, the light is scattered by the cloud particle and reaches the viewpoint. When the light is scattered only once before reaching the viewpoint, it is called single scattering component. However, inside the clouds, the light is scattered multiple times as shown in the figure. The multiple scattering component is also important for clouds. Furthermore, since the clouds are surrounded by the atmosphere, the light is also scattered and attenuated by the atmospheric particles. Such atmospheric effects are also important for the appearance of the clouds. Finally, the light behind the clouds also reaches the viewpoint through the clouds. These factors should be taken into account to compute realistic colors of clouds.

Many methods have been proposed for rendering clouds taking into account these physical phenomena. Let us review previous methods by classifying them into real-time and offline methods.

3.1. *Real-time rendering of clouds*

Real-time methods usually use GPUs to accelerate the computation involved in the rendering process. Stam used a 3D hardware texture mapping function to display gaseous objects (Stam, 1999). With the help of the high-end graphical workstation, the method can generate realistic images in real-time by combining 3D textures and advecting cloud textures by using the method developed by Max et al. (1992). We proposed a splatting method to render clouds interactively (Dobashi et al., 2000). The method