A Model of Skylight and Calculation of Its Illuminance

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Abstract. It has still been extremely expensive to make outdoor scenes illuminated by direct sunlight and skylight because of the limited models of these light sources and expensive algorithms of rendering. In this paper, a multi-layered parallelepiped is proposed for representing skylight and direct sunlight sources; the total energy of their light is regulated due to time and the position of a scene to be rendered. With this model, the illuminance on a calculation point is calculated. Then two methods for reducing the calculation cost, grouping and classifying obstacles, are discussed. This model makes a good trade-off between the cost and accuracy of rendering, and gives solar penumbra effects with a low cost.

Keywords: skylight, direct sunlight, spatial coherence, penumbra.

1 Introduction

It is desirable that an image created for visual environmental assessments is as realistic as possible and takes into account the effects of weather and the position of the sun. There are many discussions on the models of direct sunlight and skylight and algorithms for rendering outdoor scenes illuminated by both direct sunlight and skylight; e.g., shading models taking into account skylight were presented\cite{2-3}\cite{5}. In \cite{2}, when the illuminance of skylight is calculated by using C.I.E. model, the skylight source, a sky dome, is divided into some band sources; the bandwidth at the center is wider than that at its both ends. The precision of illuminance near the center of each band is much lower than that close to the both ends. As the energy of skylight near the sun is much higher than that far from the sun, if the position of the sun is at the zenith, the high precision of illuminance cannot be expected unless using very narrow bands. In \cite{5}, a parallelepiped as a model of the skylight was proposed; the algorithm of rendering is simpler and the accuracy is higher, but the solar penumbra effects cast by direct sunlight are calculated separately. \cite{1} and \cite{6} displayed the sky and the earth considering the scattering and absorption of light in the atmosphere. The effects of specular reflection considering the spectral distributions were described in \cite{7}. Solar penumbrae taking into account the size of the sun were depicted in \cite{3}. The transmission effects of skylight passing through glass were proposed in \cite{4}. The problems in every method mentioned above are still their high cost in making
animation. One basic reason is that the models of direct sunlight and skylight are limited; it makes rendering algorithms complicated.

Taking into consideration the trade-offs between the physical accuracy of a lighting model and its calculation cost, we set the following assumptions.

- The light sources are restricted to direct sunlight and skylight, and only in a clear sky; direct sunlight and skylight are much stronger than the light due to interreflection, so the latter is ignored.
- The intensity of skylight arriving at one’s viewing point is determined by the energy of atmospheric scattering. This energy is distributed on the surface of a hemispherical dome.

We propose a parallelepiped with multi-layered structures as a model of direct sunlight and skylight. With it, not only is the calculation cost of illuminance reduced drastically and reasonable accuracy achieved, but also the effects of diffuse and specular reflections of both the direct sunlight and skylight, and the solar penumbra effects can be easily unified into one algorithm.

2 Parallelepiped with Multi-layered Structures

In a previous paper [5], skylight was modelled by employing a parallelepiped with a uniform mesh on each face. However, the energy of skylight is, in fact, distributed non-uniformly; the energy near the sun is much stronger than far from it. To balance the energy for each element, an additional layer surrounding the sun is added onto the center of the top face of the parallelepiped (see fig. 1(a)) and this layer is densely meshed. We call the top face the first layer and the additional layer the second layer. When the illuminance of skylight and shadow information are calculated, the top face is divided into 11×11 elements and the 3×3 elements close to the center of the top face are replaced by the second layer with 9×9 elements. The number of elements on the other faces are calculated automatically by using the optimal curve according to the solar altitude [5].

The sun has a finite size and contributes to the solar penumbrae and sharpness of specular reflection; the third layer which stands for the sun and whose inner-tangent circle has the solid angle of the sun is added onto the parallelepiped so that the effects mentioned above can be easily and quickly calculated (fig. 1(b)). The elements outside the inner-tangent circle are set as invalid. All of the valid elements on the third layer are used just to count the proportion of sunlight arriving at the calculation point.

According to the solar position, the top face of the parallelepiped is set towards the sun and one pair of its edges are parallel to the horizon. For every element on every face and the second layer, the energy is integrated taking into account atmospheric scattering, and contribution of skylight considering its solid angle is calculated in the same manner as [5]. The total energy in these elements is equal to that of all skylight. The energy of the direct sunlight is:

\[ I_{DS}(\lambda) = I_0 e^{-t(\lambda)}, \quad \lambda = \text{the wavelengths of } r, g, \text{ and } b \text{ resp.} \]  

(1)