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REMOTE SENSING APPLICATIONS OF THE EXTENDED RADIOSITY METHOD

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Abstract

In this paper we describe the progress made in the last three years on developing the radiosity method for remote sensing applications. The research covered canopy modeling, volumetric scattering and atmospheric corrections for future analysis of EOS imaging spectrometer data.

1 Introduction

Within NASA's Remote Sensing Science (RSS) program the authors have studied applications of the radiosity method in remote sensing. The first application was in modeling the scattering of light inside vegetative canopies. We developed a program to solve the radiosity equations for the scattering of light from many scattering leaves above a ground surface. Using raytracing, we developed methods to compute the bidirectional reflectance distribution function (BRDF) of canopies. We also conducted reflectance measurements on an artificial plant canopy composed of 12000 circular disks that simulate leaves. The measurements showed good agreement with the radiosity calculation. The second application was to model the scattering between a surface and a scattering or volumetric medium to represent an atmosphere. A flat surface with a reflectance map was placed under a uniformly scattering medium and the surface and volume radiosities were computed and then rendered for a given view direction. Third, from this extended radiosity method we were able to formulate a method to compute the point spread function for any view direction and with height-dependent atmospheric scattering parameters and phase functions. Using an inverse filtering method we were able to sharpen images blurred by the adjacency effect. The method involved the deconvolution of the measured radiances with an inverse point spread function. Fourth, we are currently developing hyperspectral applications of the radiosity method for EOS-sensed vegetated and bare surfaces with imaging spectrometers.

2 Canopy Modeling

Initially we introduced the radiosity method to model the the multiple scattering and transmission in plant canopies. We developed a radiosity code for a canopy composed of circular discs placed in N layers with M discs each. Each disc i is described by the center location (x_i, y_i, z_i), the normal vector $\vec{n}_i$ and radius r_i. The view factors are computed by raytracing and a large view factor matrix with $(N \times M)^2$ elements is stored in a file. We performed radiosity calculations for various canopy geometries with up to 9,000 discs in 0.5 to 11.5 hours of CPU time on a VAX 8600. More recently we solved a radiosity problem for 14400 disks in 21.75 hours on a small workstation (SUN SPARCstation IPC). The 6 million view factors where stored in compressed form using 24 MB of disk space. The conceptual principles of the radiosity method were described in [1]; the algorithm is described in detail in [4]. Methods to include skylight were derived and implemented. A layer-based radiosity program was developed to run on an IBM PC-AT. Bidirectional reflectance distribution functions (BRDF) were computed for various illumination and observation conditions using a raytracing program. The influence of skylight and varying leaf reflectance/transmittance values on the angular signature was investigated.

Next we worked on verifying the radiosity solution with the help of a theoretical model and measurements on an artificial plant canopy structure. We were able to compare the radiosity solution to a classical radiative transfer (RT) solution for canopies with horizontal leaves. Analytical expressions as well as numerical results were compared and found to agree perfectly. By computing the up- and down-fluxes at each layer using weighted sums of radiosities of other layers, we derived that the radiosity equations lead to the classical RT differential equation for the limit of a continuous canopy structure, cf. [5]. An interesting effect of enhanced brightness on sunlit discs in lower layers for highly reflective discs ($\rho > 0.9$) was predicted using the radiosity method and experimentally verified on our simulated artificial canopy.

The radiosity method for problems with many surfaces takes much computer time and therefore, we tried to develop simpler, though still radiosity based plant canopy models. The simplification is possible when leaf layers are considered rather than individual leaves. We expanded a N-layer model to include leaf layers with inclined leaves and computed view factors between layers using a Monte Carlo approach. Once the resulting radiosity equations are solved we use standard probability based canopy models to compute the BRDF's as illustrated in [4].

3 Applications of the Extended Radiosity to Atmospheric Corrections

The extended radiosity method consists of two coupled systems of equations [2, 3] when applied to a combined canopy/atmosphere problem. The first one describes the radiosity B_i^s coming from a surface A_i as the sum of the emitted radiative flux E_i^s, the reflected fraction of radiosities from all visible surfaces and the reflected radiosities from all visible volume elements. The second equation expresses the flux density leaving a volume V_k as the sum of the emitted flux and the scattered fractions of radiosities from all visible volume elements and surface elements. The fractions of reflected or scattered radiosities are the view factors. In Figure 1 we show a symbolic representation of the extended radiosity method.

We implemented the extended radiosity method [3] and have used it to simulate atmospheric scattering over an inhomogeneous reflecting surface. We were able to reproduce the adjacency effect from rendering the radiosity solution. One major drawback of the presently implemented code is that it requires a large number of multiplications for each iteration in a Gauss-Seidel method. We think that adaptive meshing techniques, i.e. fine space subdivision near the surface and then more coarse subdivision further away will improve the computation time drastically. We believe that the extended radiosity method will provide a general purpose simulation tool for remote sensing applications which is able to incorporate surface-surface, surface-volume and volume-surface effects using computer graphics methods. The radiosity solution is global i.e. for a given illumination condition any view of the scene or inside the scattering volume can be rendered. Other methods such as the Monte Carlo method require new solutions for changing view angles. Thus by taking advantage of the global illumination calculation, effects of view angles and observer positions can be studied. Radiosity solutions can be obtained for any wavelength band in the visible and near infrared.

We also developed a method to compute the point spread function using part of the extended radiosity equations. The point spread function $PSF(x, y, z; x_0, y_0, z_0; \theta_r, \phi_r)$ is defined as the scattering contribution of a surface element $dA = dx\, dy$ located at (x, y, z) into the line-of-sight direction of the observer (θ_r, ϕ_r) looking at point (x_0, y_0, z_0). One can model the blurring effect due to the adjacency effect with a point spread function (PSF). This PSF is a filter function which is convolved with the unperturbed (no atmosphere) image of a surface. We describe this work in more detail in these proceedings [2]. Using an inverse filtering method it is possible to compute an inverse point spread function which when convolved with the measured radiance image reduces the adjacency effect considerably, which is equivalent to an atmospheric correction algorithm.

4 Modeling Terrain Effects

We are developing algorithms to compute radiosity solutions for digital terrain models (surface-surface scattering) and are trying to include BRDFs in our radiosity calculations using spherical harmonics to express the BRDFs and the radiosity at each surface.

5 Future Work

We are now in the process of integrating these various applications of the radiosity method into a simulation program which computes the surface-surface, surface-volume, volume-surface and volume-volume interactions that are of importance in remote sensing. This work will probably done on a massively parallel computer like the Connection Machine (CM-2 or CM-5).

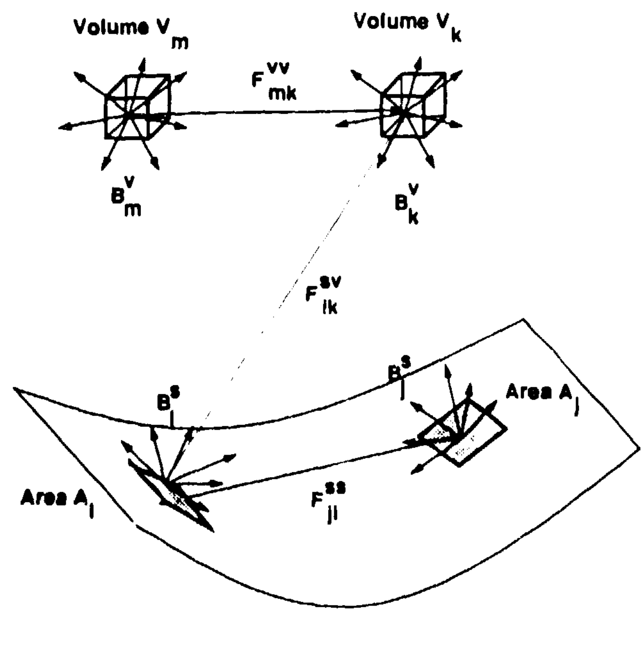

Figure 1: Visualization of the extended radiosity method for a remote sensing application including atmospheric and topography effects.

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