International Communications in Heat and Mass Transfer 38 (2011) 646–651

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Simplex ray-object intersection algorithm as ray tracer for Monte Carlo simulations in radiative heat transfer analysis ☆

H. Naeimi, F. Kowsary *

School of Mechanical Engineering, University College of Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Available online 8 January 2011

Keywords:
Monte Carlo
Ray tracing
Simplex algorithm
Linear programming
Radiation
Heat transfer

ABSTRACT

In the thermal radiation analysis via Monte Carlo method, considerable computational resources are consumed to find the intersection point of an emitted energy bundle with radiant enclosure walls. Therefore, an efficient algorithm for ray-object intersection in complex geometries may cause saving time and computational effort. This paper presents a new ray-object intersection algorithm based on the well-known simplex method from linear programming. This algorithm works by searching a point in the feasible region which is defined by a set of plane equations of enclosure boundaries that maximize the line equation of the emitted energy bundle as the objective function. This algorithm is examined for two benchmark problems, namely two parallel plates with gray specular surfaces and a box with gray diffuse walls both in three-dimensional case. Although the computation time of the new proposed method is a bit higher than the conventional time, it is easy to implement because simplex algorithm is readily available as separate module in most programming languages. By using this algorithm number of objects which must be checked in complex geometries will be reduced considerably.

1. Introduction

In many applications, such as in radiant enclosures Monte Carlo method [1–4] is a proven robust tool for calculating the radiative distribution factors [4] among enclosure surfaces, especially for those which have complex three-dimensional geometries and directional surface properties. The earliest usage of Monte Carlo method in radiation heat transfer applications seems to have appeared in the early 1960s by Fleck [5,6] and Howell and Perlmutter [7–9]. Monte Carlo method may solve accurately even the most complicated thermal radiation problems with relative ease. Currently due to rapid growth in computer speed, memory and availability, the Monte Carlo method has evolved from an expensive and very approximate estimation tool to an accurate cost-effective approach with a large number of rays, usually exceeding several million to be traced to obtain reasonable accuracy in complex thermal radiation problems. As each ray bundle can independently be considered in Monte Carlo calculations, the method is quite suitable for parallel programming. The disadvantage of this method is that, as a statistical method, it is subject to statistical error.

Since in Monte Carlo radiative heat transfer applications, results are attained by tracing a statistically significant numbers of “photons” or “energy bundles”, an efficient ray tracing method may result in a lower computational cost for the practical applications. The kernel of a ray tracing method is the determination of the intersection point of the emitted energy bundle with the enclosure walls.

Many ray-object intersection algorithms have been proposed for computer graphics applications in which ray tracing may be used for surface rendering, shadowing, etc. These algorithms can also be used in radiative heat transfer applications to determine the intersection point. Some of these algorithms are used to determine the intersection of a ray with the primitive objects such as ray-sphere, ray-box and ray-quadric intersection algorithms [10] which are used for grid traversal in grid tracing methods or where these simple objects are used as bounding volumes. The ray-plane intersection algorithm consists of two parts: 1) finding the distance to plane [10] and 2) checking if the candidate intersection point lies within the polygon [11]. In the first step only planes in which their surface normal points toward the direction vector of the ray and those that are in front of the plane are searched for intersection, otherwise intersection is rejected without any further calculation.

Although numerous methods for ray-object intersection have been reported in the literature, the most general and powerful one includes three steps [12]. First, eliminating the origin point, which will always be one intersection point. Next, eliminating the back-facing points, that is, the ones behind the emission surface. Finally, of the remaining front-facing points, the legal intersection point is the one nearest to the emission point.

The standard ray-polyhedron intersection method tests the emitted ray against each polygon to find the closest intersection. In this method convex polyhedron is considered as a space inside a set of

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: fkowsari@ut.ac.ir (F. Kowsary).

0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2010.12.019