2D Time Domain Geometrical Optics with Ray Tracing Accelerated by Binary Space Partitioning

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Time Domain Geometrical Optics (TDGO) coupled with ray tracing is a widely used high frequency asymptotic method for the simulation of wireless channel. Ray tracing is slowed down when the reflecting scene becomes complicated and the number of rays is increased sharply. Binary Space Partitioning (BSP) is one of the most successful methods of acceleration for ray tracing in computer graphics. In this paper, BSP is applied in the ray tracing firstly coupled with TDGO in the modeling of wireless propagation. The performance of acceleration of BSP is investigated. Then the result of TDGO accelerated by BSP is compared with a full-wave electromagnetic simulating method, the finite difference time domain (FDTD), and the error of TDGO is analyzed.

***Index Terms*—ray tracing, time domain geometrical optics, binary space partitioning, acceleration.**

I. Introduction

WIRELESS propagation has been widely investigated with numerical simulation taking the advantage of saving cost. Time Domain Geometrical optics (TDGO) [1] has been proved to be an efficient approach for prediction of the wireless channel. Ray tracing is a procedure of determining the trajectories of radio propagation before the simulation of physical reflection. However, ray tracing based on images is suffering from the inefficiency of visibility-testing [2]. Among the methods of acceleration, Binary Space Partitioning (BSP) achieves certain results. BSP [3] is a well-known data structure of pre-treatment to divide space in computer graphics. The unique attempt of ray tracing speed up by BSP in electromagnetics [4] is just coupled with GO in frequency domain without analysis of accelerating performance. To the author's knowledge, there is no attempt of ray tracing speeded up by BSP for TDGO.

In this paper, the Binary Space Partitioning method is implemented to accelerate the reflection in 2D imaging ray tracing. In the section II, the structure of BSP is introduced. The performance of BSP is discussed. In the section III, The basic theory of TDGO is introduced. TDGO with acceleration is validated with FDTD excited by an impulse wave. Finally, the conclusion is given in the section IV.

II. Acceleration with Binary Space Partitioning

A. Structure of Binary Space Partitioning

The hitting test of 2D ray tracing depends on the view-direction of each current ray, which is called view-dependent. In this case, the testing of visibility has to be performed during the ray tracing and extremely complicates the algorithm. The BSP tree provides a simple view-independent structure of polygons and makes the testing of visibility can be achieved before the ray tracing. The original idea of BSP tree is dividing the set of polygons in the whole scene into smaller sets, where each subset is a convex set of polygons [3]. The polygons in a convex set are visible to each other, so the hitting-test of the rays propagating in the convex set can be omitted.

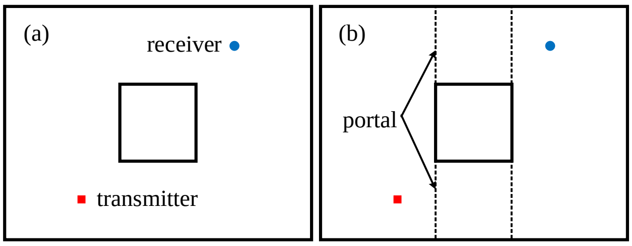

Fig. 1. The partition by the BSP tree: (a) a point transmitter and a point receiver in a room with a pillar which are modeled by two rectangle frames; (b) after partitioning, the space is separated as 5 convex sets so that each polygon in the subset is in front of every other polygon in the same set. The sets are connected by the virtual portals which are represented as dotted lines.

According to the original idea of BSP, the target is partitioning the geometrical scene in figure 1 (a) into the convex polygons in figure 1 (b). Every two convex sets are connected by a portal in figure 1 (b). The rays propagate into the next convex set by transforming through the portals. The hitting points are the intersections of the connecting lines between every two images which are reciprocal causations. The imaging procedures are iterated until the maximum hitting time is matched or the propagating distance is larger than the maximum distance. Then the rays are traced among the images by connecting the hitting points.

B. Performance of BSP acceleration

Total ray number and ray tracing time are shown with respect to maximum hitting number in the figure 2 (a) and (b) respectively. With the accelerating with BSP tree, the growth is much flat comparing with the original tracing. When the maximum hitting number is 10, accelerating with BSP saves more than 4/5 tracing time. The acceleration with BSP tree for ray tracing based on image is effective as the acceleration for SBR. With SBR method, the rays are launched uniformly from the source and then cannot be guaranteed to arrive at the receiving point [2]. Compare with SBR, imaging ray tracing is suitable for the simulations requiring more accuracy such as the localization. The efficiency of the acceleration with BSP for imaging makes the ray tracing based on image more practice for channel modeling.

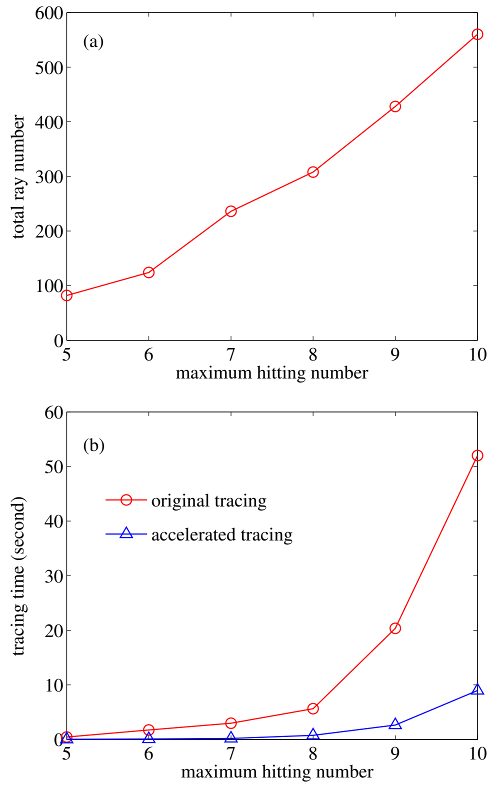

Fig. 2. The performance of accelerating: (a) total ray number and (b) tracing time, with respect to the maximum hitting number respectively.

III. Time Domain Geometrical Optics with Acceleration

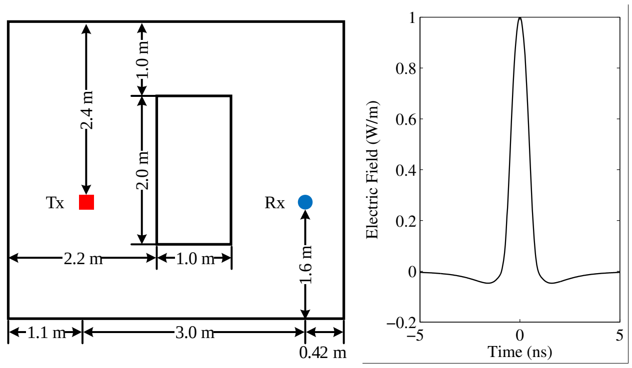

Fig. 3. Scenes and exciting waveform for validation

The 2D TDGO is validated by an impulse signal propagating in an ideal rectangle frame representing a blocked room as shown in figure 3. The material properties of the layered walls are the relative permittivity $\varepsilon_r = 10$ and the electric conductivity $\sigma = 0.1$. A point dipole and a point detector are involved to simplify the transmitter and receiver, respectively. TDGO is validated by the comparison to FDTD in figure 4. The FDTD simulation is carried out using an isotropic and uniform grid with cell size dx = dy = 8.3 mm and time step dt = 17.68 ps.

The phases of TDGO and FDTD results are matched for the vertical polarization. But with the paralleled polarization, the phases are not matched. Only the reflection is considered in the current GO algorithm and the diffraction is ignored. This is the primary cause of the disagreement. The uniform theory of diffraction (UTD) is one effective approach to calculate the diffraction. But it will also be transformed into time domain and accelerated by BSP in the future work.

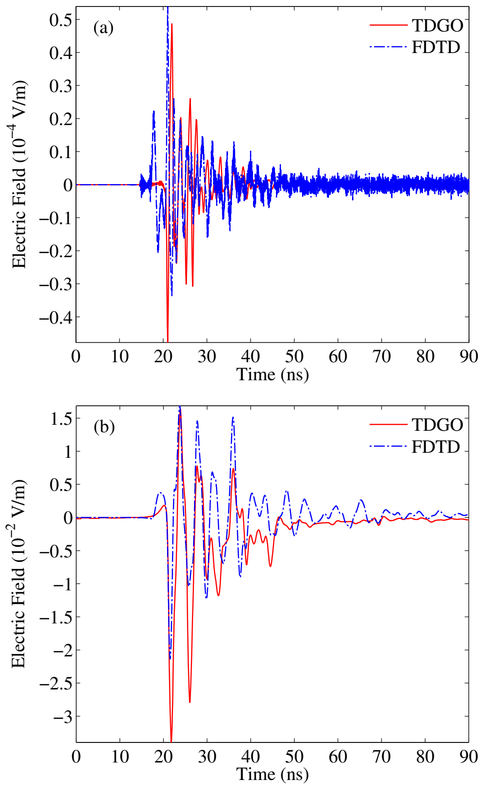

Fig. 4. Comparison between TDGO and FDTD: (a) polarization parallel to the plane of incidence; (b) polarization vertical to the plane of incidence.

IV. Conclusion

The efficiency of the acceleration with BSP tree for TDGO is proved. Then, the simulation with TDGO is discussed. Only the reflection is considered in the current TDGO algorithm and the diffraction is ignored. The further element of diffraction in time domain will be added into the algorithm and will be accelerated by BSP too.

References

[1] Robert C. Qiu, “A Generalized Time Domain Multipath Channel and Its Application in Ultra-Wideband (UWB) Wireless Optimal Receiver Design - Part II: Physics-Based System Analysis”, *IEEE Transactions On Wireless Communications*, vol.3, issue 6, Nov 2004, pp. 2312-2324.

[2] Shin-Hon Chen and Shyh-Kang Jeng, “SBR Image Approach for Radio Wave Propagation in Tunnels with and without Traffic”, *IEEE Transactions on Vehicular Technology*, vol. 45, no. 3, Aug 1996, pp. 570-578.

[3] William C. Thibault and Bruce F. Naylor, "Set Operations on Polyhedra Using Binary Space Partitioning Trees", *Computer Graphics*, vol. 21, no. 4, Jul 1987, pp. 153-162.

[4] R.P. Torres, L. Valle, M. Domingo and S. Loredo, "An efficient ray-tracing method for enclosed spaces based on image and BSP algorithm," *1999 IEEE Antennas and Propagation Society International Symposium,* vol. 1, 1999, pp.416-419.