"(POSTER) Min-Path-Tracing: A Diffraction Aware Alternative to Image Method in Ray Tracing"

Eertmans, Jérome

ABSTRACT

For more than twenty years, Ray Tracing methods have continued to improve on both accuracy and computational time aspects. However, most state-of-the-art image-based ray tracers still rely on a description of the environment that only contains planar surfaces. They are also limited by the number of diffractions they can simulate, owing to the complexity introduced when solving for paths. In this paper, we present Min-Path-Tracing (MPT), an alternative to the well-known image method that can handle diffractions seamlessly, while also leveraging the possibility to use different geometries for surfaces or edges, such as parabolic mirrors. MPT uses implicit representations of objects to write the path finding challenge as a minimization problem. We further show that multiple diffractions can be important in some situations, which MPT is capable to simulate without increasing neither the computational nor the implementation complexity.

Min-Path-Tracing: A Diffraction Aware Alternative to Image Method in Ray Tracing

Jérome Eertmans
ICTEAM
UCLouvain
Louvain-la-Neuve, Belgium
jerome.eertmans@uclouvain.be

Claude Oestges
ICTEAM
UCLouvain
Louvain-la-Neuve, Belgium
claude.oestges@uclouvain.be

Laurent Jacques
ICTEAM
UCLouvain
Louvain-la-Neuve, Belgium
laurent.jacques@uclouvain.be

I. Context

Over the past decades, Ray Tracing (RT) has gained increased interest in computer graphics [1]–[4] and telecommunication fields [5]–[8]. In both cases, RT offers accurate solutions for problems that require the simulation of electromagnetic (EM) waves, including light, interacting with the environment. Due to its high precision, but also its high computational cost, RT is mainly used as a reference solution when compared to stochastic or hybrid models, or by operators that have greater computational power available. Generally speaking, using a telecommunication terminology, RT's goal is to compute every possible path between two nodes, and later apply appropriate physical wave propagation rules. In the field of radiocommunications, the knowledge of those paths can help to determine a channel model for communication between those nodes, *e.g.*, between base station (BS) and user-equipment (UE). Then, the channel model can be used to derive some important metrics, such as the delay, power attenuation or interference level. A variety of RT implementations can be found, either with deterministic outcomes (*e.g.*, Image RT) or stochastic (*e.g.*, Ray Launching), as well as hybrid versions that try to combine both methods to obtain the best compromise: an accurate and deterministic solution at a relatively low cost. However, regarding image based RT, it seems that modern ray-tracers suffer from limitations on both the number of diffractions and the type of geometries they can handle, *i.e.*, mostly planar surfaces (*e.g.*, polygons) [9].

II. Content Description

In this paper, we describe Min-Path-Tracing (MPT), an alternative to the image method that allows us to generalize the *path finding* process, *i.e.*, the computation of all possible paths between two nodes, regardless of the type of geometries of 3-D scene or the number of diffractions encountered along the path. Our technique leverages, if available, the implicit equations of surfaces and edges in the scene to construct a minimization problem. Then, the paths coordinates—the collection of path interaction points on each surface—are obtained as solutions of this problem. As with the image method, MPT is only concerned with finding the path between two points that performs a certain list of interactions with the environment. Our method does not take into account possible obstructions that could be caused by other objects. This will be the role of the "validation" step and will be discussed in the paper. Even though our contribution is mainly focused on the path finding problem, we provide many details on all important steps in RT so that the interested reader can produce a functional RT simulation from this document. The structure of this work is organized as follows. First, we summarize the main components of modern radiocommunications-oriented RT engines and in which context our contribution takes place. Next, we establish the problem we are solving by defining appropriate mathematical objects. Since both MPT and the image-based method first require defining a list of interactions, we describe how we generate all possible lists using a directed graph-based approach. Next, we detail how the image method and our alternative work in practice, and we also provide a basic Python implementation that is made available to the reader in open access and shows on a simple example that both methods yield the same solution. After, we summarize the main steps of the computation of paths between the BS and UE nodes in a single algorithm. Then, we compute electric field contributions from different paths, in a simple urban scenario, to highlight the importance of intermediate and multiple diffractions in radiocommunications. Finally, we discuss the differences between the image-based method and the MPT method, and we give a few applications where our method could be useful, as well as future prospects.

III. Conclusion

We presented MPT, a method that overcome the inherent limitations of the image-based method in RT by both allowing for any number of diffraction and arbitrarily complex geometries. We also showed that multiple diffractions paths can play an important role in radiocommunications and being able to account for such paths is key. After, we discussed the different pros and cons of our method, such as the difficulty to compute diffraction coefficients in the situation where multiple diffractions are chained [10], [11] or how we can obtain implicit equations of every object in our 3-D scene. Finally, we explained how one could extend MPT to handle ray refraction, and other future improvements.

References

[1] A. Marrs, P. Shirley, and I. Wald, Eds., *Ray Tracing Gems II: Next Generation Real-Time Rendering with DXR, Vulkan, and OptiX*. Berkeley, CA: Apress, 2021.

[2] A. Dib, G. Bharaj, J. Ahn, C. Thébault, P. Gosselin, M. Romeo, and L. Chevallier, "Practical Face Reconstruction via Differentiable Ray Tracing," *Computer Graphics Forum*, vol. 40, no. 2, pp. 153–164, 2021.

[3] S. G. Parker, J. Bigler, A. Dietrich, H. Friedrich, J. Hoberock, D. Luebke, D. McAllister, M. McGuire, K. Morley, A. Robison, and M. Stich, "OptiX: A general purpose ray tracing engine," *ACM Transactions on Graphics*, vol. 29, no. 4, pp. 66:1–66:13, Jul. 2010.

[4] T.-M. Li, M. Aittala, F. Durand, and J. Lehtinen, "Differentiable Monte Carlo ray tracing through edge sampling," *ACM Transactions on Graphics*, vol. 37, no. 6, pp. 222:1–222:11, Dec. 2018.

[5] V. D. Esposti, "Ray tracing: Techniques, applications and prospect," in *2020 International Symposium on Antennas and Propagation (ISAP)*, Jan. 2021, pp. 307–308.

[6] F. Fuschini, E. Vitucci, M. Barbiroli, G. Falciasecca, and V. Degli-Esposti, "Ray tracing propagation modeling for future small-cell and indoor applications: A review of current techniques," *Radio Science*, vol. 50, pp. n/a–n/a, May 2015.

[7] Y. Yang, T. Li, X. Chen, M. Wang, Q. Zhu, R. Feng, F. Duan, and T. Zhang, "Real-time ray-based channel generation and emulation for UAV communications," *Chinese Journal of Aeronautics*, Dec. 2021.

[8] P. Tang, "Channel Characteristics for 5G Systems in Urban Rail Viaduct Based on Ray-Tracing," in *2021 4th International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, Dec. 2021, pp. 24–28.

[9] D. He, B. Ai, K. Guan, L. Wang, Z. Zhong, and T. Kürner, "The Design and Applications of High-Performance Ray-Tracing Simulation Platform for 5G and Beyond Wireless Communications: A Tutorial," *IEEE Communications Surveys Tutorials*, vol. 21, no. 1, pp. 10–27, 2019.

[10] D. S. JONES, "DOUBLE KNIFE-EDGE DIFFRACTION AND RAY THEORY," *The Quarterly Journal of Mechanics and Applied Mathematics*, vol. 26, no. 1, pp. 1–18, Feb. 1973.

[11] G. Carluccio, F. Puggelli, and M. Albani, "A UTD Triple Diffraction Coefficient for Straight Wedges in Arbitrary Configuration," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 12, pp. 5809–5817, Dec. 2012.