Applications of Shooting-Bouncing Ray Tracing to Modeling Propagation in Underground Mines

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This paper addresses applications of Shooting-Bouncing Ray (SBR) tracing to signal propagation modeling in underground mines. The approach outlined implements spherical-wavefront SBR with utilizing scaled observation spheres to sample the computed field. While previous work has been performed on the application of SBR and similar asymptotic techniques to wireless signal characterization of uniform structures such as railway tunnels, little work has been done toward applying and optimizing these methods for more-complicated propagation environments such as those present in mine tunnels.

We examine the convergence properties of the SBR method as it applies to uniform and non-uniform structures, and the implications of these findings for effective and efficient modeling of large, non-uniform structures such as underground mines. We demonstrate the intuitive convergence properties of SBR for simple, lossless, convex structures, and then extend these behaviors to more-complicated, non-convex structures. From these properties, we examine the useful estimates on computational resources that can be assumed to accurately model a given tunnel, offering bounds on the number of rays and reflection order necessary, as well as the relationship between these quantities.

We also discuss practical aspects associated with data collection and processing for complicated tunnel environments – most importantly aspects associated with reconstructing usable and topologically-correct meshes for use with SBR from raw data. Furthermore, we examine the practical challenges associated with collecting and processing geometric data in rough-walled tunnel environments and introduce approaches to minimize error. The methods by which we construct surface meshes and volume meshes from these data are discussed in brief. We leverage several techniques from the computer-graphics community toward our application and discuss the efficiency of the associated algorithms.

Furthermore, we examine the efficient implementation of SBR on modern computing hardware, and introduce in brief several optimizations that can be made on modern, parallel systems. We demonstrate computational speedup achievable on such systems for practical implementations.