

A Novel Differentiable SBR Framework and Its Application on Efficient Optimization for PEC Low-Scattering Shapes

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Differentiable physical simulation technology has garnered significant attention in both academia and industry in recent years. This innovative approach bridges the gap between traditional physical simulation and gradient computation, enabling the simultaneous execution of forward physical simulations and rapid gradient acquisition through backpropagation. As a result, it paves the way for efficient gradient-based optimization of complex physical problems.

In this paper, we propose a novel differentiable Shooting and Bouncing Rays (SBR) electromagnetic simulation framework tailored for electromagnetic applications. At the implementation level, our framework leverages GPU-accelerated parallel computing for ray tracing and scattered field computation, while utilizing PyTorch's automatic differentiation tools to trace computational paths and obtain gradient information, thereby achieving efficient bidirectional computation. Compared to existing differentiable finite-difference time-domain (FDTD) and method of moments (MoM) solutions, our framework supports rapid electromagnetic computations for larger-scale problems. Furthermore, unlike AI-based differentiable approaches, our framework is rigorously grounded in physical principles, eliminating concerns about generalization while maintaining the high computational efficiency.

Leveraging this framework, we have implemented gradient-descent-based optimization for low-scattering shapes of perfect electric conductor (PEC) structures. Unlike conventional approaches, our method directly manipulates vertices on the mesh, significantly reducing the need for extensive geometric preprocessing. To achieve stable vertex updates, we introduce techniques from computer graphics: (1) shape-preserving regularization (K. Tojo, A. Shamir, Be. Bickel, and N. Umetani, "Stealth Shaper: Reflectivity Optimization as Surface Stylization," *Proc. SIGGRAPH '23*, no. 20, pp. 1-10, 2023.), which prevents the optimized shape from deviating excessively from its initial state, and (2) Laplacian preconditioning (B. Nicolet, A. Jacobson, and W. Jakob. "Large steps in inverse rendering of geometry," *ACM Trans. Graph.*, vol 40, no. 248, Dec. 2021.), which amplifies interactions between vertices and suppresses surface folding. Fig. 1 presents some of the optimization results. Using our framework for low-scattering optimization, we achieve an average RCS reduction of over 10 dBsm within only a few minutes.

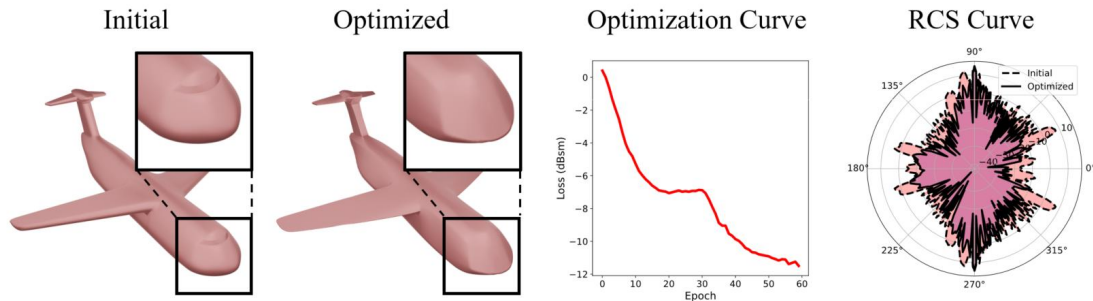


Figure 1. The optimization results of a cargo plane.