SurfelPlus: A Surfel-Based Global Illumination Solution Optimized for Low-End Graphics Hardware

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Figure 1: Comparison of real-time global illumination results produced by SurfelPlus. Left: Left half of this image is a stylized office scene rendered with full surfel-based indirect lighting, reflection, and spatial-temporal filtering. Right half of this image shows the intensity of the scene indirect lighting. Right: A classical Sponza scene demonstrates subtle light bounces and occlusion effects enabled by SurfelPlus. Both examples illustrate the effectiveness of our method in preserving detail, enhancing depth perception, and supporting dynamic lighting without requiring precomputed data.

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1 INTRODUCTION

Global illumination (GI) plays a crucial role in computer graphics, significantly contributing to visual realism by accurately simulating complex light interactions, including reflections, scattering, and indirect illumination within virtual scenes. Traditionally, high-quality GI solutions rely heavily on offline rendering methods, precomputed lighting solutions that store static illumination data and lack support for dynamic scene updates [Ren et al. 2013]. Recent approaches leverage neural networks for radiance caching to enable real-time global illumination in dynamic scenes, but such methods still entail substantial computational overhead, limiting their applicability on lower-end hardware [Müller et al. 2021]. Alternatively, expensive real-time ray tracing techniques are also employed, yet all these methods often exceed the capabilities of mainstream or low-end graphics hardware.

To address these challenges, Electronic Arts (EA) introduced a promising approach known as Global Illumination Based on Surfels (GIBS) at SIGGRAPH 2021 and further refined it at SIGGRAPH 2024. GIBS dynamically discretizes scene geometry using surface elements, or "surfels", combined with ray tracing techniques, efficiently caching and reusing indirect illumination computations. This significantly reduces computational overhead while maintaining robust support for dynamic scenes.

Building upon the foundational concepts introduced by GIBS, we present SurfelPlus, a novel surfel-based global illumination solution explicitly optimized for low-end graphics hardware. In the following section, we describe the core design and implementation details of SurfelPlus.

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2 METHOD

SurfelPlus is a real-time global illumination renderer built on NVIDIA's vk_raytrace framework, leveraging Vulkan ray tracing and surfel-based GI methods. Our approach dynamically discretizes scene geometry into surfels—point primitives storing position, normal, color, and material properties [Pfister et al. 2000]—to efficiently compute indirect lighting.

Indirect illumination is computed by accumulating and sharing radiance among surfels without precomputed lighting data. Direct lighting utilizes Vulkan's ray tracing, while indirect lighting is efficiently handled by surfels.

Our pipeline initially captures per-pixel geometry data (visibility, depth, normals) in the G-buffer. Surfels are dynamically generated and adaptively updated, with radii adjusted based on camera distance and local geometry. A recycling mechanism optimizes surfel lifecycle management.

Surfels are structured within a spatial grid for efficient neighbor queries and interactions, crucial for dynamic scenes. Surfel radiance is computed via ray-guided and cosine-weighted sampling. Rays cast from surfels interact with emissive surfaces, and stochastic sampling manages dense distributions.

Surfel radiance is aggregated using the MSME algorithm for temporal stability, and irradiance data is shared within spatial cells for rapid convergence. Dynamic surfel generation maintains uniform lighting coverage based on screen-space density.

Figure 2: Rendering breakdown illustrating the contributions of each lighting component. From left to right: Final combined rendering, Direct lighting, Indirect lighting computed via surfel-based GI, and Specular reflections.

Our implementation integrates surfel generation and per-pixel color computation into a unified pass, significantly reducing computational overhead compared to previous methods, as further detailed in the Results section.

For specular reflections, SurfelPlus employs Reservoir Importance Sampling (RIS) combined with surfel indirect lighting, enhanced by spatial-temporal and bilateral filtering for noise reduction. Additionally, we integrate Screen-Space Ambient Occlusion (SSAO) for depth cues and Temporal Anti-Aliasing (TAA) to mitigate aliasing, further enhancing visual realism.

3 RESULTS

We evaluated the performance of SurfelPlus on an NVIDIA RTX 2070 GPU at a resolution of 2560x1440 pixels. The renderer consistently achieved real-time frame rates exceeding 120 FPS, demonstrating significant efficiency improvements suitable for low-end graphics hardware.

Our proposed enhancements build upon the original surfel-based GI framework, preserving its visual fidelity while significantly optimizing computational efficiency. Specifically, by integrating surfel generation and per-pixel color computation into a unified pass, our implementation reduces performance overhead by approximately 13% compared to previous methods. Furthermore, our application of RIS combined with surfel indirect lighting, alongside advanced spatial-temporal and bilateral filtering techniques, enhances specular reflection quality and effectively mitigates rendering artifacts such as noise and flickering.

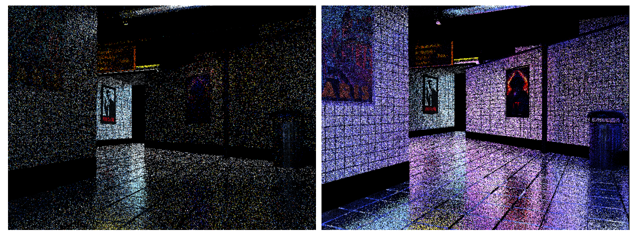

Figure 3: Comparison of specular reflection quality with and without surfel-based indirect lighting. Left: Reflections computed without surfel indirect lighting require up to 6 bounces. Right: Surfel-based indirect lighting achieves better reflection quality with only 1 bounce, significantly reducing computational overhead.

4 CONCLUSION

In this work, we presented SurfelPlus, a novel real-time global illumination solution leveraging surfel-based techniques optimized specifically for low-end graphics hardware. By dynamically discretizing scene geometry into surfels, our approach avoids expensive precomputations and facilitates real-time indirect lighting updates suitable for interactive and dynamic applications. Our optimized unified surfel generation and shading approach significantly enhances performance, while advanced spatio-temporal filtering techniques effectively suppress rendering artifacts, ensuring both visual quality and computational efficiency.

However, our current implementation exhibits several limitations. Primarily, to ensure suitability for lower-end hardware, SurfelPlus does not yet support indirect illumination for dynamically moving objects within the scene. Future work includes extending SurfelPlus to address these limitations. We also plan to integrate advanced denoising techniques such as NVIDIA's ReSTIR GI [Lin et al. 2022] to further enhance rendering quality and efficiency.

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