Details Enhancement in Unsigned Distance Field Learning for High-fidelity 3D Surface Reconstruction

细节增强的高质量无向距离场学习与三维重建

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Motivation

While signed distance fields (SDF) are favored for their capability to represent watertight surfaces, unsigned distance fields (UDFs) provide a means to model both open surfaces and objects with complex inner structures. However, achieving high-quality UDFs that accurately reconstruct 3D surfaces with fine geometric details is challenging for several reasons:

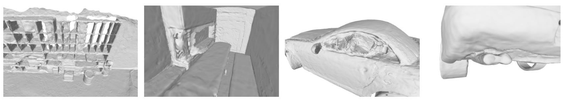
- UDFs struggle to precisely achieve a zero value, making it difficult to generate detailed surface.
- UDFs are theoretically non-differentiable at the zero level set, resulting in vanishing gradients near the target surface.
- The gradient directions of UDFs tend to oscillate near the surface, causing the reconstructed surfaces to be fragmented.

Methods

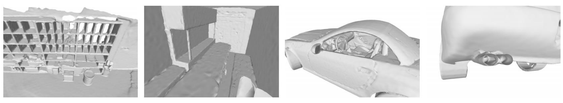
- We use unconditioned MLPs to represent UDFs and consider the local minimal distance surface of the UDF value around zero, which may be either positive or slightly negative, as the intended surface.
- A key observation is the significant role normal directions play in learning fine details. Normal directions are critical for enhancing surface details in the reconstruction process.
- Direct application of Eikonal constraints to regularize UDFs may cause the actual surface to deviate from the input point cloud and may also increase the minima of the learned UDF. To address this issue, we propose a formulation for an adaptively weighted Eikonal loss term

Results

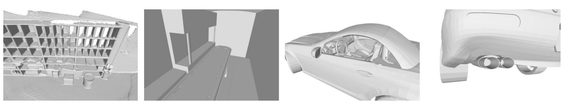
Visual comparisons with DUDF, CAP-UDF and LevelSetUDF on an indoor scene of the Stanford 3D Scene dataset featuring noise, an imperfect scan, and two car models of the ShapeNet-Cars dataset showcasing complex structures. Our method remains the open boundaries, such as, the bookshelves, inner structures of the vehicle, car window and car exhaust vent.



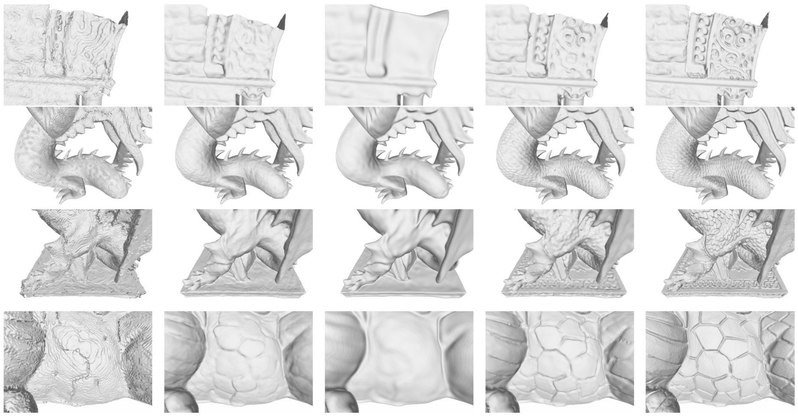
(c) LevelSetUDF



(d) Ours



(e) GT



(a) DUDF (b) LevelSetUDF (c) NSH (d) Ours (e) GT

Visual comparison with two recent UDF learning approaches, DUDF and LevelSetUDF, and one recent SDF learning method, NSH, on surfaces with fine geometric details. Our method yields visually pleasing results, reconstructing significantly more details than the other methods

Our method achieves the best performance in UDF-based methods, and performs close to SDF-base methods.