Enhancing Safety and Reliability in Autonomous Systems Through Robust Scene Reconstruction from Sparse Visual and LiDAR Data

Overview

A critical aspect of ensuring safety in connected and autonomous vehicles (CAVs) is to accurately model and reconstruct driving scenes in real-time, even with limited data inputs. In autonomous driving, for instance, the available sensor data (such as images and LiDAR point clouds) is often sparse, either due to infrequent sampling or rapid vehicle motion that leaves gaps in the data stream. These sparse data points pose significant challenges for constructing 3D scene representations that are necessary for tasks like navigation, obstacle detection, and decision-making. To address these challenges, our proposed framework, FlowReg, focuses on leveraging sparse views of a driving scene to generate robust 3D reconstructions. FlowReg utilizes camera poses, RGB images, and sparse LiDAR point clouds to build accurate 3D Gaussian-based representations. By introducing a flow-based initialization technique, we effectively extend the scene coverage beyond LiDAR reach, capturing distant geometries that are often omitted in traditional approaches. This extended coverage is crucial for CAVs operating in complex and dynamic environments where accurate scene understanding is critical to avoid potential safety hazards.

A key challenge in this sparse-view reconstruction is maintaining the accuracy of the 3D model across large camera movements, which can disrupt the gradient flow for traditional neural network-based models. This disruption often leads to overfitting, where the model excels only on the observed views but fails to generalize to novel viewpoints. Additionally, the lack of sufficient geometry supervision, especially for regions beyond the LiDAR sensor's range, exacerbates this problem, leading to distorted geometry in the reconstructed scene. Our method tackles these issues by integrating appearance and geometry-based losses, such as L1 loss, Structural Similarity Index (SSIM), and a LiDAR-based depth loss, ensuring that the generated 3D scene remains consistent across views. This approach not only improves the robustness of scene reconstruction but also enhances the reliability of autonomous driving systems by providing consistent, accurate scene representations, even in sparsely sampled and high-motion settings. Through FlowReg, we aim to push the boundaries of scene understanding in CAVs, enhancing their ability to operate safely and reliably in real-world environments where data availability is often limited or unreliable.

Keywords

Autonomous systems; robust scene reconstruction; sparse visual data; LiDAR sensors; safety and reliability; machine learning

Broader Impact

This research has significant potential to improve autonomous driving, robotics, and simulation applications by enhancing 3D scene reconstruction using optical flow to regularize Gaussian splatting. By addressing challenges such as sparse-view data and inconsistent geometry, we ensure better generalization to novel viewpoints and more accurate simulations. The method's ability to generate high-quality reconstructions from limited data can advance road safety, immersive AR/VR experiences, and urban modeling. It also contributes to broader AI-driven perception and planning systems, fostering innovation across various industries.

Project Leads

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