Radiance Fields for Robotic Teleoperation

Maximum Wilder-Smith[1], Vaishakh Patil[1], Marco Hutter[1]
[1]Robotic Systems Lab, ETH Zurich

RSL
Robotic Systems Lab

1 Introduction

Motivation: Mobile manipulation robots have potential to perform remote maintenance and inspection in complex environments such as transit tunnels, greatly reducing downtime.

Objective: To enable high quality teleoperation Neural Radiance Fields (NeRFs) and 3D Gaussian Splatting (3DGS) perform realtime reconstruction from a ROS robot; with the visualization being streamed to a VR headset for teleoperation.


NeRF render of a switchboard cabinet captured on ALMA, being used by a VR teleoperator

2 Contributions

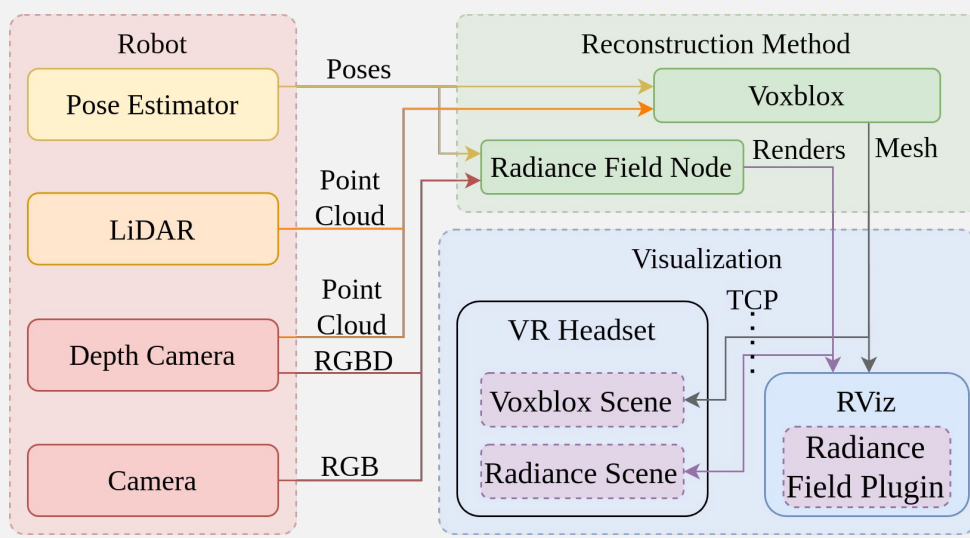Three contributions to the state-of-the-art are presented:

1. Create realtime radiance fields from online robot ROS data

2. Support for multiple methods ranging from traditional **meshes**[1], to **NeRFs**[2] and **3DGS**[3]

3. Visualization tools that allow radiance fields to be viewing in RViz on a screen, or streamed to a VR headset
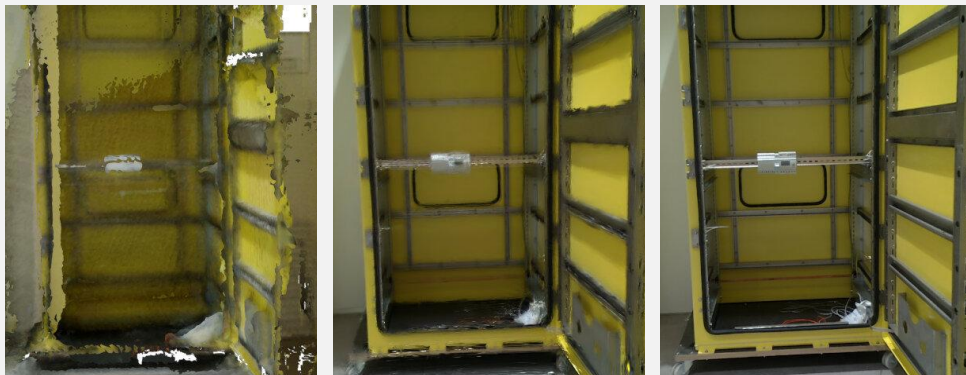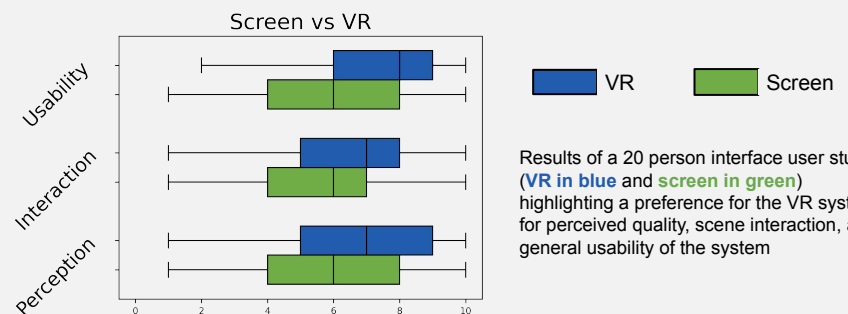

Comparison of switchboard cabinet reconstructions with mesh on the left, NeRF in the center and 3DGS on the right

3 System Overview

1. The robot sends poses and sensor data to the reconstruction
2. Data creates a radiance field (3DGS or NeRF) or mesh
3. Reconstruction is sent to VR and screen-based visualizers

4 Results

Results of a 20 person interface user study (**VR in blue** and **screen in green**) highlighting a preference for the VR system for perceived quality, scene interaction, and general usability of the system

Method	PSNR ↑	SSIM ↑	LPIPS ↓
Mesh	16.94	0.5140	0.5295
NeRF	22.16	0.6473	**0.1478**
3DGS	**24.59**	**0.7414**	0.2126

Photometric comparisons of different 3D reconstruction methods with the radiance fields out performing the mesh

Method	Per Iteration Time [ms]	PSNR of 16.94 db [s]	Render Time [ms]	Render Time [FPS]
Mesh	1205.903	165.470	-	-
NeRF	35.644	7.027	1020.131	0.980
3DGS	**34.651**	**6.996**	6.6257	**151.0**

Timing comparisons to integrate new data, reach the final quality of the mesh reconstruction, and render time

5 Conclusion

- Radiance field digital twins produce high fidelity renders of novel environments

- Both radiance field methods can reach high quality reconstructions faster than mesh based systems

- 3DGS can render novel views in real time, allowing for teleoperation using a VR headset

Acknowledgement

References

1. Helen Oleynikova, et al, "Voxblox: Incremental 3D Euclidean Signed Distance Fields for On-Board MAV Planning", IROS, 2017
2. Ben Mildenhall, et al, "NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis", ECCV, 2020
3. Bernhard Kerbl, et al, "3D Gaussian Splatting for Real-Time Radiance Field Rendering", ACM, 2023

Partner: amag SBB CFF FFS SIEMENS

CSFM