Multi-Goal Robot Exploration and Inspection

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Motivation

- Autonomous inspection enables consistent monitoring of safety conditions and maintenance status across factory facilities
- High-fidelity 3D reconstructions provide a detailed historical record of facility states, enabling temporal analysis and detecting changes.

Problem description

- In this work, we explore training agents for **Multi-goal Inspection** in complex environments to produce **High-fidelity 3D reconstruction** of these goals.
- We define a set of Goals $\mathcal{G} = \{g_0, g_1, ..g_N\}$ of size N that we wish to cover.
- Each goal has an inspection quality $f(g_i)_{\geq 0}$.
- Our algorithm's objective is to maximize the sum of inspection quality across all goals:

$$\mathcal{J} = \max \sum f(g_i)$$

Approach

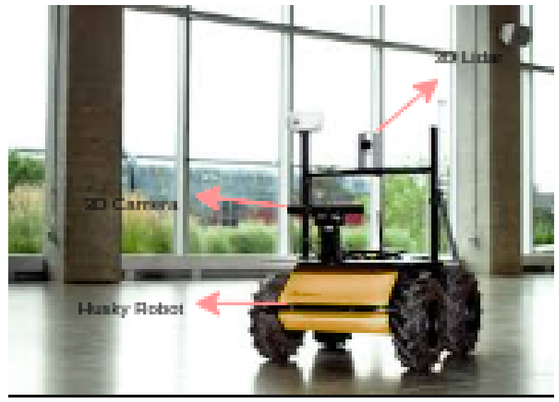
The proposed approach is divided into two main modules.

1. Vision-based Reinforcement learning agent for navigation and Inspection.
2. Gaussian Splatting for 3D reconstruction and Novel View Synthesis.

Hardware and Sensor Configuration (Proposed)

We plan to implement our approach on a Husky Robot with the following sensors:

- 3D Lidar: Sensor for Mapping, Localisation and Collision avoidance purposes.
- 3D Camera (PTZ Camera): he camera is mainly for taking high-fidelity images. The camera's PTZ (Pan-Tilt-Zoom) capabilities will be integrated into the robot control and action space.



Inspection Software Modules

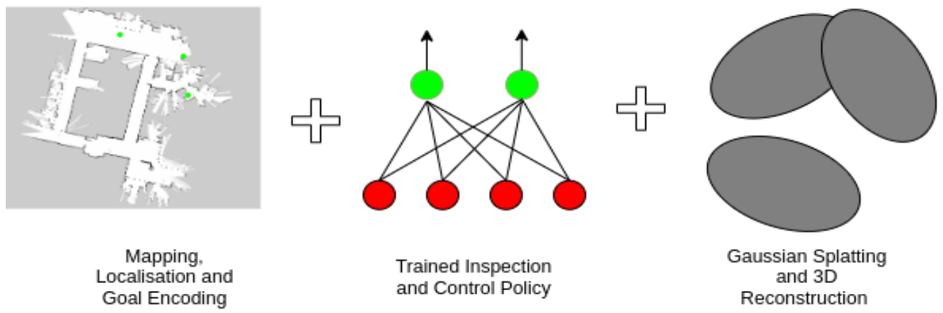


Figure: Three main modules running on our Robot for our inspection task.

1. Mapping, Localisation and Goal Encoding
2. Control and Inspection Policy
3. 3D Gaussian Splatting

- We assume that our system has a Map of the environment as well as an encoding of goals we wish to inspect
- The control and planning are executed by a Neural Net trained through RL, the trained policy is responsible for navigating to the Goals as well as deciding when and where to take images for high-fidelity 3D reconstruction.
- The last Module runs Gaussian Splatting, a fast Novel-View-Synthesis algorithm that creates high-fidelity 3D rendering from Images and a clever fast Rasterisation from 3D Gaussian.

Proposed Inspection experiments

- We intend to train our Control and Inspection Policy in Isaac Sim
- Experiments will involve testing Sim-2-Real capabilities aimed at developing algorithms robust enough to transfer from simulation to the real-world Husky Robot
- To ensure generalization capability, we will import diverse industrial equipment and machine models as inspection goals during training.
- The system will be implemented using Robot Operating System (ROS) 2

Inspection Evaluation

1. For a given set of Inspection goals size N, we evaluate each goal's reconstruction quality as $f(g_i)$.
2. The Inspection evaluation per task is evaluated as $\frac{1}{N} \times \sum_{i=0}^{N} f(g_i)$.
3. Reconstruction quality is measured by the pixel-wise visual error between images from 3D reconstruction (Gaussian Splatting Module) and sampled images from the Simulator with the same camera pose.

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