SS 2024-2025, SMT-ROB, DISAL-MP59 Project Summary

Safe Navigation in Environments Represented by a Gaussian Mixture Model

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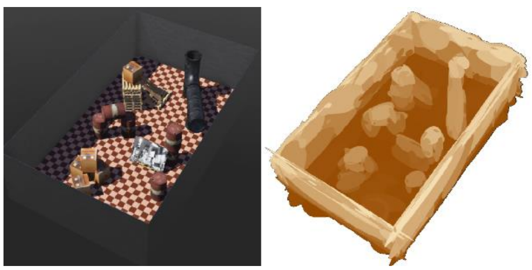
Autonomous and safe drone navigation typically relies on classical environment representations such as voxel grids or occupancy maps. These methods are easy to use but have certain limitations, notably high memory usage and discrete, non-differentiable representations. Recently, Gaussian Mixture Models (GMMs) have emerged as a continuous, compact, and differentiable alternative, where obstacles are represented as sets of Gaussians with varying sizes and orientations.



Sparse environment (Webots/GMM map)

In this context, my project aims to evaluate the viability of GMM-based environments for safe autonomous drone navigation. The project's objectives are:

- To identify, adapt, implement, and evaluate three state-of-the-art planning methods in GMM environments.
- To select the best-performing method and implement it in real-time using ROS, validated with Webots simulations.

The three methods selected to be implemented in Python are Covariant Hamiltonian Optimization for Motion Planning (CHOMP) (Ratliff et al., 2009), Splat-Plan from Splat-Nav (Chen et al., 2024), and Polynomial Trajectory Planning (Richter et al., 2016). All three methods optimize a seed path generated by RRT* (Karaman et al., 2011). CHOMP minimizes a cost combining obstacle avoidance and trajectory smoothness. Splat-Plan constructs a polytope corridor around the seed path before optimizing Bézier splines within the corridor. The Polynomial method fits polynomial curves (degrees 5, 7, or 9) between the seed path waypoints, minimizing snap (the fourth derivative of position).

The three methods were evaluated in two environments with distinct obstacle densities. For each environment, 200 seed paths were generated, resulting in 1200 evaluated trajectories.

The method demonstrating the best overall performance was the polynomial trajectory planning method (Richter et al.). It was implemented in C++ with ROS for real-time validation. The simulations in Webots showed satisfactory results, producing smooth, safe, and rapidly optimizable trajectories.

RViz vizualisation of the polynomial trajectory

This project demonstrated the ease with which existing methods can be adapted to GMM-based environments. It validated the feasibility of using GMM representations for real-time drone navigation and confirmed that representing obstacles with Gaussians ensured safe navigation.

However, the project highlighted some limitations. Occasionally, optimization takes longer than expected or struggles to produce a feasible trajectory, especially in narrow, obstacle-dense corridors. The Polynomial approach performed best in open spaces. Furthermore, its computational cost remains high, making onboard real-time implementation challenging. Finally, the project lacks a baseline comparison with traditional methods, thus not proving that using GMMs improves performance compared to voxel-based environments, but rather demonstrating their usability.