Carnegie Mellon University
Computer Science Department

THESIS PROPOSAL

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Approximate Continuous Belief Distributions for Exploration

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Efficient, robust robotic exploration has the potential to solve significant challenges and save lives when disasters occur underground. Cave rescues to extricate trapped or lost spelunkers are difficult and demanding endeavors performed dozens of times each year in the United States in environments that are often neither mapped nor surveyed and have limited to nonexistent communications due to the convoluted nature of underground voids. Underground nuclear waste storage facilities become inaccessible to humans when radiation leaks occur, so efficient pose estimation and mapping to localize radiation leaks is of the utmost importance. Catastrophic sinkholes appear suddenly in areas of karst terrain throughout the United States, swallowing homes, and trapping residents in debris.

Without reliable communications, robots must operate autonomously to efficiently explore these subterranean environments, but many Simultaneous Localization and Mapping (SLAM) techniques do not generate maps fit for active perception. Occupancy grid map techniques are typically used after solving the SLAM problem to generate feasible trajectories. The advantage of occupancy grid maps is they may be updated quickly, but the gains in speed come at the cost of either memory efficiency or fidelity. In exploration contexts, systems maneuvering in large environments must elect to decrease the resolution of the occupancy grid map in order to mitigate explosive memory demands or suffer increasingly slower speeds when manipulating occupancy grid maps with small cell sizes. For computationally constrained systems, the latter is prohibitive, but employing low-resolution environment representations has significant disadvantages. For example, small passageways and hazards may be obscured and rich details obliterated.

Gaussian Mixture Models (GMMs) are well suited to compactly represent sensor observations and model the structural correlations present in the environment. These generative models are advantageous as compared to voxelized representations that assume independence between cells and lose dependencies between spatially distinct locations. GMM-based perception tasks such as registration have been studied, but solutions are either not real-time viable or have not been evaluated with large real-world datasets. There are few works that address the viability of leveraging these models for tasks such as SLAM and exploration, because a significant challenge to overcome is the time needed to create these models.

This thesis proposal seeks to develop a SLAM framework with GMMs from which occupancy may be readily derived to enable robust and efficient exploration. The result will be the unification of compact generative models of the environment with occupancy modeling techniques to enable exploration with respect to a high-resolution map that has low memory footprint and is amenable to local and global pose updates. This is possible through innovations made in work completed thus far, which include a baseline exploration framework that leverages occupancy grid maps, robust distribution to distribution registration, and a method for deriving occupancy from GMMs at arbitrary resolution. The proposed work aims to improve exploration performance and computational efficiency by (1) developing a SLAM framework that leverages GMMs to compactly describe 3D LiDAR sensor observations; (2) formulate a method to detect previously visited locations and close the loop, and (3) embed the notion of occupancy in the framework and demonstrate the performance of exploration strategies that leverage this high-resolution environment representation. We also propose to evaluate the developments in simulation and onboard an aerial system equipped with a LiDAR in caves.

Thesis Committee:
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Thesis Summary: https://www.dropbox.com/s/ymomib8ed73mktg/thesis_proposal.pdf?dl=0