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Real-Time Long-Term Navigation with CUDA-Accelerated 3D Grid Map

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Abstract – In the landscape of robotics applications, the pivotal role of occupancy grids in preserving environmental data cannot be overstated. This significance becomes particularly pronounced in the realm of Simultaneous Localization and Mapping (SLAM), where mobile robots dynamically navigate and scan their surroundings. Addressing the challenges posed by loop closure detection, FRAGG-Map—an innovative 3D grid expressly crafted to optimize efficiency during sustained, long-term exploration. Diverging from conventional methods, FRAGG-Map minimizes the necessity for map reconstruction at loop closures, thereby enhancing overall operational efficiency.

Keywords - *SLAM, Efficient-Mapping, GPU-Acceleration, Real-time, Long-term-exploration*

I. Introduction

In robotics, occupancy grids are essential repositories of environmental information, particularly in applications like Simultaneous Localization and Mapping (SLAM), where robots navigate dynamically. Extended missions pose challenges related to loop closures and grid expansion. Traditional maps, such as OctoMap, face limitations in real-time updates during loop closures due to the complexity of the Octree when huge areas are explored, hindering applicability for long missions. FRAGG-Map, a Frustum Accelerated Gpu-Based Grid Map, designed for efficient map updates. Utilizing a highly parallelizable 3D grid and OpenACC/CUDA kernels, FRAGG-Map streamlines point cloud insertion and deletion, enabling real-time updates. The key feature is the use of field of view to identify the portion of the map that must be updated and then parallelize insertion and deletion of point clouds. This allows a robot to have a map always updated without having to rebuild a whole map at loop closures as happens for tree based maps. CUDA-optimized methods enhance its capabilities for tasks like frontier computation and collision-checking during extended missions, outperforming literature algorithms in point cloud operations and matching memory consumption.

II. Method description

In pursuit of enhanced processing speed compared to OctoMap, our approach involves the development of a novel structure utilizing OpenACC and CUDA. Departing from Octrees, we adopt a 3D grid, akin to a linear array, facilitating parallelization of functions for efficient conversion into CUDA kernels or optimization using OpenACC. The grid resides in the CPU, with a submap loaded into the GPU, characterized by resolution, initial cell count (N), and a list of cells loaded in the GPU. Each grid cell, sized at 8 bytes, holds an integer denoting the points added and a float representing occupancy probability. Additionally, we use the concept of frustum, a geometric shape in computer graphics representing the visible region on the screen. Unlike OctoMap-server, which distributes volumetric 3D occupancy maps, our frustum-based approach proves advantageous in conserving resources during scene rendering. Despite encountering obstacles, the frustum aids in determining free and safe navigation spaces, even when no points are detected in the point clouds. This innovative method ensures the occupancy probability is updated by considering visible cells within the frustum and the sensor's range, proving particularly effective in scenarios where space occluded by obstacles is not represented.

III. Versatile Applications of FRAGG-Map: Enhancing Efficiency in Long-Term Exploration and Collaborative Robotic Missions

Exploring the diverse applications of FRAGG-Map unveils its nuanced contributions to efficiency and adaptability in various scenarios. This section delves into two applications of long-term exploration: solo and collaborative robotic missions.

1) Long-Term Solo Exploration**:** In this scenario, it is important for the robot to have an understandable map all along the exploration. It is also important that the map is updated in real-time since collisions are possible and in order to make the right decision, the robot must have knowledge of the world. This scenario can be enriched by adding a docking station. In this case, the robot can perform multiple missions while exploring different places and have the same map updated during the whole mission.

2) Multi-Robot Exploration: Map Fusion and Communication

In multi-robot exploration scenarios the focus is on efficient map fusion and communication. The communication can be achieved by integrating LUMA optical modems. Real-time collaboration ensures the creation of a unified map, allowing robots to share obstacle data and discoveries instantly. The use of advanced communication protocols, coupled with LUMA optical modems, not only reduces collision risks but also facilitates quicker decision-making in dynamic environments.

IV. CONCLUSIONS

In this paper we presented the utility of FRAGG-Map, an innovative real-time occupancy grid mapping solution designed for long missions and exploration. Noteworthy for efficient loop closure handling through frustums and GPU-accelerated ray-tracing, FRAGG-Map optimizes computational resources. Its truncated mapping allows flexible management and seamless collaboration. Future enhancements may include semantic mapping integration for intelligent environment interaction and integration with GTSAM for precise loop closure updates.

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