Application of Motion Planning Algorithms in SLAM

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SLAM and Motion Planning

Motion planning algorithms and simultaneous localization and mapping (SLAM) are closely related fields in robotics, with one often being used to aid the other. Motion planning algorithms are used to plan safe and efficient paths for robots to navigate through unknown environments, while SLAM is used to construct a map of the environment and estimate the robot's location within it. The two fields overlap in that motion planning algorithms rely on accurate maps of the environment and knowledge of the robot's location in order to plan safe and efficient paths, while SLAM benefits from the motion of the robot, which helps to improve the accuracy and completeness of the map. Thus, motion planning algorithms can aid SLAM by providing additional information about the environment, while SLAM can aid motion planning by providing an accurate map and location estimate for the robot to use in its path planning.Fig 1 shows a map generated as per the approach by drone flying through the blocks hence creating a trajectory(orange in colour).

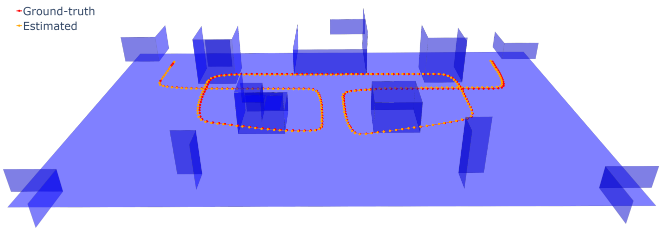

Figure 1: Simultaneous Localization and Mapping

1 Point Clouds in SLAM

PlaneSLAM, a 3D LiDAR SLAM algorithm for Manhattan-style environments that extracts planar features from point clouds for real-time localization and mapping has been presented in [1]. The algorithm generates lightweight, plane-based maps that are suitable for fast collision checking in motion planning. By assuming a Manhattan world, the algorithm is able to extract structured, orthogonal planes for efficient map generation. The approach is tested in simulation and on a real-world rover with a Velodyne LiDAR, achieving high-quality maps and trajectory estimates at 10 Hz in [1].

The Research paper explains that while established methods such as LOAM and its variations are accurate and real-time, the maps they produce are point clouds that grow rapidly in memory and are not suitable for direct use by motion planners. The paper also mentions that extracting planes from point clouds is not a new idea, with methods such as RANSAC, the Hough transform, and point cloud segmentation being commonly used. It also references prior works that have explored plane-based registration and SLAM, such as Pathak et al., Grant et al., and Favre et al., but notes that these works do not consider the problem of motion planning within their plane maps [1]. The paper claims that their work is unique in highlighting the advantage of plane maps for fast and efficient motion planning, and in producing more structured and organized maps for Manhattan world environments.

To conclude, a plane-based LiDAR SLAM algorithm for real-time lightweight map generation and localization has been presented in [1]. The algorithm generates plane-based maps which occupy less memory than point cloud equivalents and are suited for fast collision checking for motion planning. The algorithm is designed to integrate with motion planning algorithms and is tested with a ground rover equipped with Velodyne LiDAR, which shows high quality maps and trajectory estimates at a rate matching the sensor rate of 10 Hz.

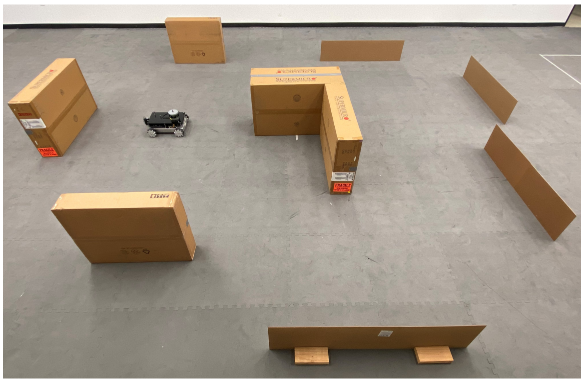

Figure 2: Rover in the Box environment

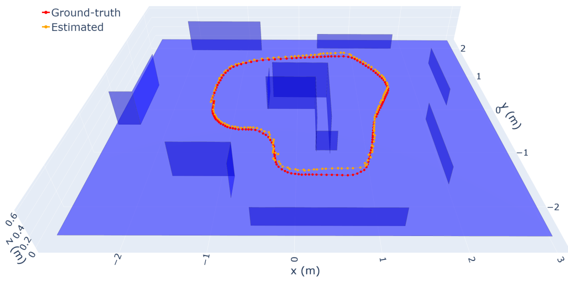

Figure 3: Rover map and trajectory

2 Path Planning of indoor Substantiated Autonomous Robots

A new navigation system for indoor substation robots to improve staff safety is presented in [2]. The new system uses a mobile chassis with autonomous navigation and positioning capabilities, which allows the robot to perceive its surroundings and find a suitable path to the target point using its own sensors. The system uses a combination of odometer and inertial navigation data, fused together using the Extended Kalman Filter, to create a map of the environment. The global path is scheduled using the A* algorithm and the local path is scheduled using the Dynamic Window Method. Different global path planning algorithms for robot navigation, including Dijkstra, A*, Probabilistic Road Map (PRM), and Rapidly Exploring Random Tree (RRT) have been discussed in [2]. The Dijkstra algorithm is a breadth-first search algorithm that finds the shortest distance between two points, but has a high time and data cost. The A* algorithm improves the efficiency of Dijkstra by adding a heuristic function. The PRM algorithm samples points in the environment and connects them to form a map, but can be difficult to use in narrow and long areas. The RRT algorithm randomly samples postures and expands a tree until the destination is reached, but the route may not be the shortest. The A* algorithm is chosen as the preferred global path planning algorithm, and a comparison of its running time with the Dijkstra algorithm is provided in a table.

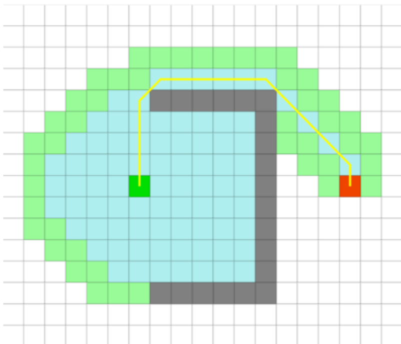

Figure 4: Result of the Algorithm run

To summarize, the paper presents a 3D LiDAR-based navigation system for indoor substation robots, which allows the robot to perceive the surrounding environment information at the initial position using its own sensors and find a suitable path to move to the target point to complete the task. The system is based on multi-sensor data fusion, robot navigation path planning, and automatic stopping and obstacle avoidance. The system is tested and implemented on a switchgear auxiliary operating robot, and the results indicate that the system contains the necessary indicators and demands for the distribution switchgear auxiliary operation robot project. However, there are still deficiencies in the design of the current navigation system, such as the inability to continue to run to the target point when there is a fixed obstacle below the scanning range of the LIDAR. Future research will focus on solving these problems and improving the applicability of the model in complex environments.

3 Maps and Autonomous Navigation

A complete online system for autonomous navigation of mobile robotic systems is presented in [1]. The system consists of three modules: incremental SLAM, real-time dense mapping, and free space extraction. These modules work together to generate accurate maps for motion planning and control. The system is designed to run in real-time and has been tested on the KITTI dataset, with results showing good performance in terms of mapping accuracy and run-time efficiency. The source code for the system has been made publicly available for the benefit of the community.

Dense 3D maps are essential for autonomous robotic navigation as they provide the perception input for path planning, mobile manipulation, and other tasks. Traditional methods for creating such maps involve two stages: estimating the poses of sensors (such as cameras and laser scanners) and sparse features/semidense textures using SLAM algorithms, and then creating a volumetric dense map by projecting 3D points/range scans/disparity maps onto the correct global poses. However, updating these maps in real-time can be computationally expensive, especially when large-scale loop closures are detected. Recent methods have been proposed to address this issue by incorporating all SLAM updates as soon as they become available and creating temporally consistent maps. However, these methods still have challenges such as running offline or assuming known camera poses, and lack of real-time performance at video frame rate.

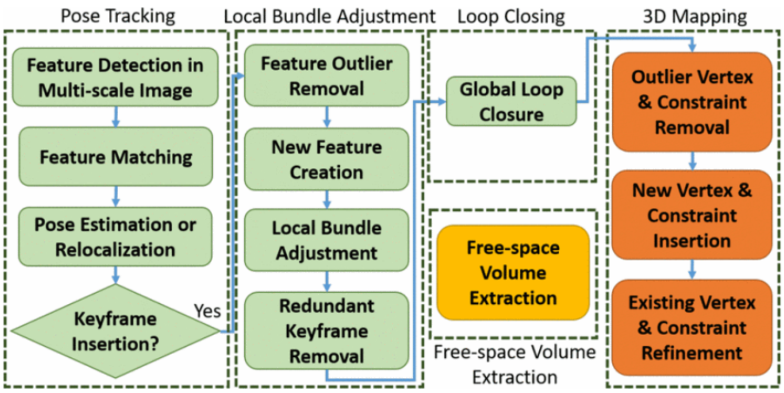

Figure 5: System Pipeline

In summary, the system described in Fig. 5 utilizes a multi-core architecture and runs five threads simultaneously. The system follows a feature-based SLAM pipeline, similar to ORB-SLAM2, for tasks such as pose tracking, local bundle adjustment, loop closing, and global optimization. The system also includes a 3D mapping module that converts optimized sparse features into dense volumetric representation and a free-space volume extraction module that outputs free-space volumes for path planning.

Summary

The recent advancements in motion planning and its algorithms have the potential to revolutionize the field of SLAM in the coming years, just as it has undergone a drastic change in recent years. With the integration of motion planning techniques, the system will be able to navigate through unknown environments with greater accuracy and efficiency. The technology will allow for more robust and reliable navigation in dynamic environments, and will open up new possibilities for autonomous systems. The combination of motion planning and SLAM will not only improve the performance of current systems but also pave the way for new applications in various fields such as robotics, drones, and self-driving cars. The future looks bright for the field of motion planning and its impact on SLAM and we can expect to see significant advancements in this area in the coming years. I look forward to contribute into this evolving technology.

References

1. Dai, Adam, Greg Lund, and Grace Gao. "PlaneSLAM: Plane-based LiDAR SLAM for Motion Planning in Structured 3D Environments." arXiv preprint arXiv:2209.08248 (2022).

2. Ren, Jianxin, et al. "SLAM, Path Planning Algorithm and Application Research of an Indoor Substation Wheeled Robot Navigation System." Electronics 11.12 (2022): 1838.

3. Y. Ling and S. Shen, "Building maps for autonomous navigation using sparse visual SLAM features," 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, Canada, 2017, pp. 1374-1381, doi: 10.1109/IROS.2017.8202316.