AER1516 Project Proposal

Furqan Ahmed, Matt Brymer, Vandan Rao, Sangita Sahu

Autonomous UAVs, including quadrotors, have become commonplace in applications such as aerial photography, outdoor surveillance of industrial assets and package delivery. They are increasingly being tasked with operation in dense environments such as forests, urban or indoor spaces where the world map may not be known apriori. The combination of a larger number of obstacles and only partial observability of the world in these applications makes the problem of motion planning more difficult and requires methods that are capable of rapidly generating trajectories based on new information that are safe, smooth and dynamically feasible. Producing algorithms that can meet these needs while still being feasible for onboard computation is still an area of active research.

The quadrotor system dynamics possess the property of differential flatness, namely that the state and required control inputs can be directly computed from a set of flat output variables. For the quadrotor it can be demonstrated that the combination of the position and yaw angle satisfy this property, meaning that almost any given trajectory can be achieved given it lies within the control input limits[1]. This natural agility and flexibility has lead to a variety of approaches to the motion planning problem. Some authors have explored sampling based methods, where at each replanning step an array of possible trajectories based on motion primitives are sampled and one is selected for execution based on some cost criterion. These motion primitives are in some cases based on optimal control theory results for minimum time or jerk motions[2][3]. These methods offer closed form solutions that enable very fast replanning times, but do not necessarily guarantee optimal behaviour over larger time horizons. Others have explored graph search based methods based on minimum time motion primitives, some even with collision checking based on the quadrotor's attitude and an ellipsoidal body[4][5]. While these approaches are powerful, they are often too expensive to be run onboard on computationally constrained platforms.

One promising class of methods that have emerged are hierarchical motion planners. These methods consist of a fast global planner that produces an initial path to the goal location based on some minimum cost heuristic that is then refined in a subsequent optimization step. Their inherent modularity has lead to variety of different techniques being studied for each component in the literature. The global planning step is typically performed with a graph search technique such as Jump Point Search (JPS) or A* [6][7]. The trajectory is then parameterized, often with a piecewise polynomial trajectory or Bezier curves, and an optimization problem is solved to minimize some form of motion derivative or trajectory time [6][8][9]. Collision checking may be performed during the optimization step either against observed points in the world map[7] or a convex decomposition of the world[8]. Constraints to keep the trajectory dynamically feasible can be implemented by sampling the trajectory[8] or by utilizing the convex hull property of b-splines[7]. Some techniques plan only in the known free space for safety[7], while others assume the unknown space is free to allow for faster flight speeds but also maintain a safe backup trajectory[6]. These techniques often involve solving a constrained QP[1], but in some cases lead to a MIQP if trajectory segments are not fixed to specific constraint sets[6].

Given the successes of these hierarchical planners, we plan to implement a hybrid approach that leverages the strengths of the various components demonstrated in previous works. Our proposed architecture is as follows:

- Global Planner - JPS[10] for shortest piecewise linear path
- World Map - Sliding occupancy grid derived from a depth map
- Environment representation – Polyhedral convex decomposition of free space derived from world

map and global trajectory[8]. Utilize convex hull property of Bezier curves for collision checking

- Path parameterization – Set of Bezier curves, each fixed to specific polyhedron
- Dynamic feasibility – Convex hull property of Bezier curves
- Cost function – Minimize norm of jerk squared plus trajectory time (weighted)
- Optimization problem – Constrained QP
- Safety – Plan within known free space only

It should be noted that our proposed plan closely resembles the structures of FASTER and Fast-Planner while being slightly simpler, suggesting it should be a feasible approach. If the proposed QP framework does not produce good results then we will revert to the original MIQP formulation within FASTER.

We will implement the planner in a series of ROS modules and test it in Gazebo simulations in randomized environments such as simulated forests or indoor spaces. We plan to evaluate it based on metrics such as success rate, trajectory time, peak velocity and code execution time. Assuming no compatibility issues, we will aim to compare our results against the implementations of other authors on similar metrics, possibly including FASTER, Fast-Planner or a sampling based planner[11]. Time permitting, we may explore adding a backup trajectory similar to FASTER to enable faster flight by safely planning within the unknown space.

References

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