Planning Aggressive, Dynamically Feasible and Optimal Trajectories for Autonomous Vehicles in Cluttered Environments using Mixed Integer Programming

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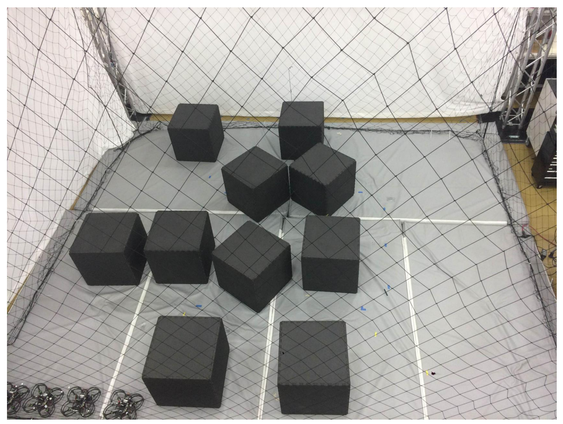
Research Objective and Challenges

Objective: Plan aggressive trajectories in densely cluttered environments via a computationally tractable algorithm, resulting in a complete methodology that yields optimal and dynamically feasible trajectories.

Challenges: Generating feasible and safe trajectories in cluttered environments is computationally expensive due to the need to consider a large number of obstacles.



Densely cluttered test environment. We generate aggressive trajectories for the above environment with a maximum velocity of 4 m/s.

Approach

- Develop efficient path planning algorithm for Unmanned Aerial Vehicles (UAVs) using Mixed Integer Programming Solution for minimum-snap collision free trajectories. [1]
- This approach scales with the number of regions rather than the number of obstacles.

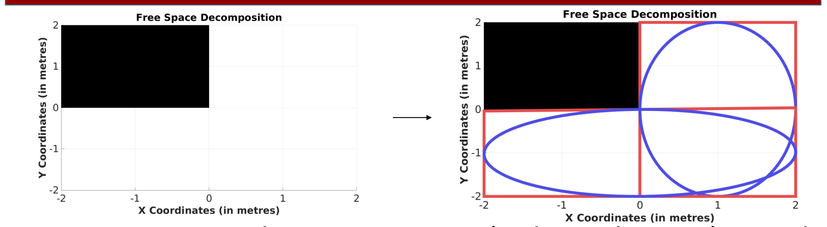
Methodology

- Given a bounded volume (environment) with obstacles and a goal position, we compute convex regions of space that are free of obstacles.
- Resulting regions fill the free space via a proposed automated seed-point selection approach.
- Generate a smooth trajectory from start to goal while remaining inside the environment volume.
- Free Space Decomposition via IRIS [2] constrains trajectory optimization formulation.

Optimization based Trajectory Generation

- Mixed-Integer Second Order Cone Program (MISOCP)
- Convert linear equality constraints to linear inequality constraints for solving MISOCP
- Trajectories are assigned to convex safe regions by running MISOCP on numerically easier degree 3 polynomials.
- Fix resulting safe regions and calculate trajectory durations.
- Semidefinite program enables minimum snap higher order polynomial trajectories

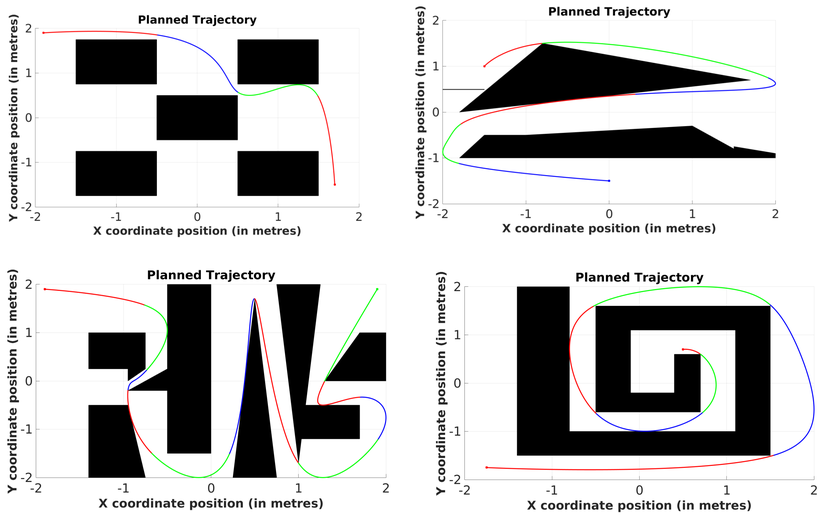
Free Space Decomposition Example



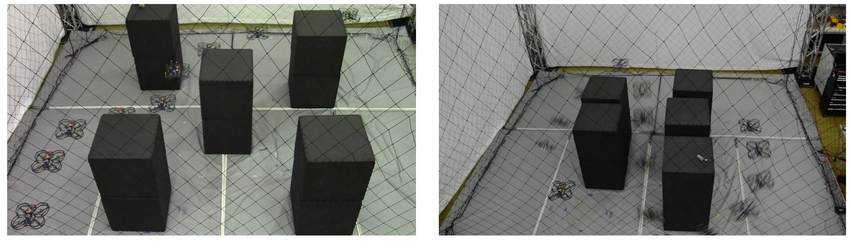
- Free space decomposition (red polytopes) and environment obstacles.

Results

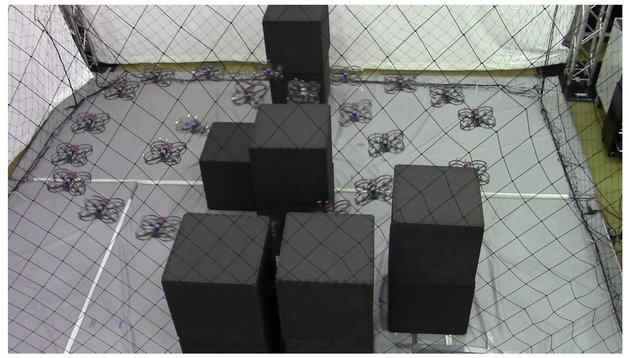
- Environments yield increasingly complex planning scenarios.



Feasible and Safe Aggressive Flight in Environments 1 and 2



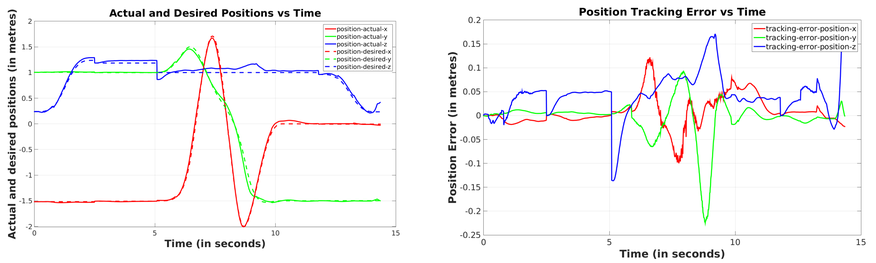
Environment 1 *Environment 2*

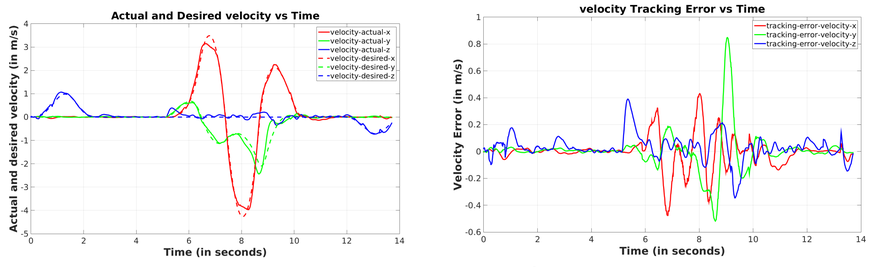


Aggressive Flight in Environment 4 (multiple images overlaid to show a complete trajectory)

Analysis of System Performance

- Tracking errors with respect to position and velocity for Environment 2





- Achieves a maximum velocity of 4 m/s with limited tracking error (position and velocity)

Conclusion and Future Work

- We generate dynamically feasible and safe trajectories to enable fast flight in densely cluttered environments.
- In the future, we will pursue a probabilistic free space approach to enable automatic map generation as well as, an online approach toward enabling autonomous navigation.

References

1. Deits, R., & Tedrake, R. (2015, May). Efficient mixed-integer planning for UAVs in cluttered environments. In *2015 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 42-49). IEEE.
2. Deits, Robin, and Russ Tedrake. "Computing large convex regions of obstacle-free space through semidefinite programming." *Algorithmic Foundations of Robotics XI*. Springer International Publishing, 2015. 109-124.