3D Path Planning for a UAV with Flyable and Safety Constraints

Nehchal Jindal (nehchal@gatech.edu)
Proposal
CS7649
Georgia Institute of Technology

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are increasingly being deployed by the military to tackle rising terrorism and crime, for combat and reconnaissance, as well as surveillance purposes. Amazon, an online retailer, recently announced its plan to use UAV for package deliveries in the city. UAVs are also being put to use for topographical mapping of a region [13]. Thus, a large range of potential applications of UAVs in military and civilian sector has generated a lot of academic as well as commercial research [7]. Despite the advance in robotic motion planning since 1970s, autonomous navigation of UAVs is still an active research area. In this research project, we look at path planning of a UAV in an urban environment, where obstacles such as buildings may be present.

Path planning in UAVs is challenging due to the complex kinematic and dynamic constraints on the path. In particular, flyable paths should satisfy curvature and torsion constraints [6]. Curvature constraints limit the maximum curvature (radius of turning) on the path. Similarly, torsion constraints limit the rate of rotation of UAV about the axis that coincides with tangent of the path. Since the environment may contain known or unknown obstacles, safety constraints mandate the non-intersection of paths with obstacles or other UAV. For the purpose of this project, speed of the UAVs is assumed to be constant, which is the case for fixed-wing UAVs.

While several solutions for path planning for UAVs are available, but either they are computationally intensive, not optimal or do not satisfy all constraints. In this project, we attempt to improve upon existing path planning algorithms. Successful completion of the project would certainly help in taking the field forward.

II. REVIEW OF LITERATURE

Path planning of UAVs in 2D has been widely studied over the past decade or so. Many ideas have been drawn from ground robotics research. The general problem dealt is to find smooth enough trajectory given positions and poses of the UAV at start, final and intermediate waypoints. These studies have considered curvature constraints, but torsional constraints are ignored as UAV is always assumed to be in horizontal pose. Bortoff [1] describes a method for modeling of UAV trajectory using a series of point masses, located at waypoints, connected by springs. Threats or obstacles exert repulsive forces on the masses, causing the trajectory to move away from threats, and generating smooth path. Beard et. al [2] use similar approach for path planning of multiple UAVs for coordinated rendezvous. Several researchers have used Dubins curves [8] [9] [10] to produce smooth curves. This algorithm produces smooth paths from start to end point via waypoints, using concatenation of straight lines and circular arcs. This method does satisfy the curvature constraint but does not satisfy curvature continuity. [6] [11] claims that discontinuity in curvature can cause difficulty for practical control implementation, in that a UAV cannot instantaneously change its behavior as it crosses the segment boundary. [2] uses a modified version of Dubin curves, called clothoid curves, which generate curvature continuous paths. However, no closed-form expression can be found for position for clothoid curves [12], thus making it computationally intensive. [3] generates piecewise linear paths between consecutive waypoints, and then uses cubic Bezier spiral curves to generate a continuous curvature path that satisfies the minimum radius of curvature constraint.

Path planning of UAVs in 3D environments has not been widely researched. [3] proposes a method to extend the idea of path smoothing in 2D using cubic Bezier spiral curves to 3D environments. [5] uses Dubins curves in 3D to generate paths. None of these consider torsional constraints and obstacles. [4] uses Pythagorean hodograph (PH) curves for path planning in 3D environments. These meet curvature as well as torsional constraints. PH curves are curvature continuous too. But, PH curves produce longer paths than Dubins path, since they don’t contains any straight segments [6]. [4] further tunes to flyable paths obtained from PH to make them safe from obstacles.

III. PROJECT DESCRIPTION

A. Problem Statement

Unmanned aerial vehicles (UAVs) are increasingly being deployed in dangerous situations, military combats, surveillance and civilian purposes. The aim of path planning is to facilitate moving or flying of UAV from one location to another. Intermediate points (waypoints) may be specified which have to visited before reaching the target. The pose of the UAV can be precisely specified by location (x, y, z) and orientation (θ, ψ). Additionally, map of the environment is also provided specifying all the obstacles.
Given the location/pose of the UAV at start, final and waypoints, UAV needs to plan its path to reach the target. We assume that UAV has constant speed, which is the case in fixed-wing UAV which allows minimal changes in speed owing to its specific design. The hardware poses certain kinematic constraints. Hence, paths obtained should be flyable by the UAV. More specifically, paths should follow maximum-curvature and maximum-torsion bounds. The problem being tackled is planning paths for UAV satisfying flyable and safety constraints in 3D environment with obstacles.

B. Project Scope

This research project is expected to come up with novel method for path planning of UAVs, in 3D environments with obstacles. Apart from that, project will help me personally to grasp the concepts and techniques in path planning. In addition, it is expected to help the UAV research community by contributing to UAV path planning research. The methods devised in this research project will be simulated for validation and evaluation. With above said, the project does not takes into account other dynamic or static UAVs, or unknown obstacles that may be present in the environment. Re-planning on detection of unknown obstacles is not considered. Coordinated planning with multiple UAVs is another interesting area of research, but it has been left out for the purpose of this project.

C. Project Objectives

The major project objectives include:
1) Simple path path planning in 3D environment without obstacles.
2) Path planning, satisfying flyable constraints, in 3D environment without obstacles.
3) Path planning, with flyable and safety constraints in 3D environment with obstacles.
4) The simulation of the devised methods for path planning.

D. Research Approach

The project will be broken down into simple subtasks. Initially, environment without obstacles will be considered. We will try to incorporate torsional constraints on the path into the algorithm. If that is achieved, then we will look at simple obstacles (for eg. spheres or cuboids) and try to tune our path to include safety constraints (avoid obstacles). One of the current ideas is to use Dubins path in 3D environments. These may not have continuous curvature but will lead to smaller paths than paths calculated using pythagoras hodographs. Due to lack of curvature continuity, UAV may deviate a little from its planned trajectory because of difficulty in control, but that should be acceptable. This would save fuel and time as compared to PH curves. We can try to build up on this idea to incorporate torsional constraints.

Finally, we run the simulation for the devised methods.

E. Project Deliverables

The project deliverables are as follows:
- The final report outlining the work done and results obtained.
- The videos/images for relevant simulations

IV. LIMITATIONS

The major limitation is the small size of team (currently only one member), which seriously affects the man-hours devoted to the project. Unfamiliarity with UAV modeling and simulation may be a further constraint.

REFERENCES