Vector field path following and obstacle avoidance singularity mitigation via look-ahead flight envelope

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ABSTRACT

Problem Statement

Unmanned Aerial Vehicles (UAVs) conventially navigate a series of off-line generated and initially obstacle free waypoints that may have to be re-planned when encountering a previously unknown obstacle. Re-planning waypoints could be avoided by implementing a path following and obstacle avoidance vector field guidance. Guidance to converge and follow a pre-planned path is produced by an attractive vector field while obstacles are represented by a repulsive vector field. Summing together attractive goal and repulsive obstacle fields produce a guidance for tracking a pre-planned path while avoiding unplanned obstacles. Small regions of null guidance, called singularities, may be produced when summing attractive and repulsive fields together.

Method for path following, obstacle avoidance, and detection / mitigation of vector field singularities for UAVs etc

Motivation

- Conventional waypoint guidance relies on a pre-planned, flyable, and obstacle free path
- Obstacles unaccounted for during planning may require a re-plan which may require communication with a ground station

Background

- Vector field guidance for path following has been shown to be both robust in the presence of external disturbances and produce low cross track error flight
- Obstacles can be represented as repulsive fields and summed with attractive fields to produce an obstacle avoidance guidance
- Summing vector field guidance my produce singularities, resulting in no guidance
- Repulsive fields currently provide no additional information on how to go around obstacle

Contribution

- Method for compensating for singularities that may be experienced (Lookahead or fast detection)

I. Nomenclature

VF = Vector Field

II. Introduction

Unmanned Aerial Vehicles typically move through the environment by navigating a series of pre-planned and off-line generated waypoints. An on-board guidance system typically generates a desired heading based on the current active waypoint and the current position of the UAV. Once the UAV breaches the radius of the waypoint, guidance transitions to the proceeding waypoint. During waypoint navigation the UAV may encounter a previously unknown obstacle or change in the environment which may require a new obstacle free series of waypoints be generated. Dynamic environments may require frequent waypoint re-planning which may be difficult or impossible if communication with the ground station responsible for waypoint generation is lost.

(More information on path planning)

Potential field models a robot's workspace as a gradient potential of attractive and repulsive artificial forces [k].

- UAS consists of vehicle, autopilot, ground station, radios

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- Missions typically pre-planned on ground station where flyable and obstacle free paths can be generated. (Figure of conventional waypoints)
- Waypoints are sent to the autopilot over a radio and received and interpreted by the vehicles autopilot
- Autopilot responsible for navigating waypoints while maintaining vehicle stability
- Due to turn rate constraints or external disturbances, a vehicle may not follow the path perfectly where it may encounter an obstacle previously planned for
- Demonstrate the above with dubins
  - Introduce dubins as a way to approximate a UAVs dynamics, assume control working (cite)
  - Equations
  - Demonstrate Dubin's UAV not perfectly following path
  - Demonstrate Dubin's with wind not following path
- Reduced error for straight line and circular path following has been achieved by using vector field guidance (sujit)
- Continuous vectors that asymptotically converge and follow straight and circular paths are both robust and produce guidance that results in low cross track error
- Lyapunov VF primitives introduced (Nelson). Nelson stitched together primitives to produce complex paths similar to navigating waypoints
- Curved path vector field was introduced in (griffiths)
- Goncalves VF
  - Path of any shape
  - Accounts for TV nature of paths
  - Field is produced by summing convergence and circulation terms that are easily accessable
  - Integral lines guaranteed to converge
- Obstacles considered in standoff tracking scenario Wilhelm
  - TV field loiter around moving ground target
  - obstacles represented by repulsive field
  - Did not consider or identify singularities present in summed fields
  - Singularities are small regions or wells of no guidance where UAV may be trapped
  - No information on how to go around obstacle
  - Field used as a high level specification for avoidance
  - Hyperbolic activation function
- Activation functions of obstacle avoidance investigated in Zhu
- Determining VF parameters that influence performance and singularity location

III. Methodology

A. Singularity Detection

- Present VF equations for straight path following
- Present VF equations for circular obstacle and obstacle definitions
  - Repulsion, small 'path' radius
  - Decay function
  - No circulation versus circulation (side by side figure)
- Sum fields together and show stages of normalization
- Identify pre normalization singularity
  - Surface plot (x,y,magnitude)
  - Identify undefined region and singularity (Evaluating entire space)
  - Find minimum of guidance function by evaluating several initial conditions
  - Method for finding all singularities as a reference to future look-ahead methods
- Look-ahead and singularity detection
- Location of all singularities not important if UAV is not going to encounter them
- Introduce UAV flight envelope
- Time, turn rate, constant velocity, produces possible locations of UAV
- Evaluate ICs on flight envelope when near obstacle

B. Modifying VF to avoid singularities

- Cause and location of singularities
  - Adding circulation to the repulsive obstacle field reduces /removes singularity
  - Singularities will occur where both fields have equal strength
  - Prediction of singularity location based on decay function
- Side by side repulsion and repulsion+circ singularity locations
- Singularity detected, modify field to remove singularity from flight envelope
- Objective function is:
  - Avoid obstacle
  - Avoid singularities
  - Minimize deviation from path

IV. Simulation

- Dubins UAV following a pre-planned straight path
- Obstacle encountered
- A guidance solution must be determined that:
  - Determines location of singularities if present (inside flight envelope)
  - Solve VF parameters to remove / mitigate singularities
  - Solve VF parameters that result in guidance that minimize error from path
- Various UAV speeds
- Worse case scenario presented (on path)
- Multiple obstacles on path (sequential)
- Compare non-modified guidance with modified guidance
  - Deviation from path
  - Yes/no obstacle avoided
  - singularity avoided in flight envelope

V. Conclusion

Appendix

Acknowledgments