A Proposal for a Parameterized Circulating Vector Field Guidance for Fixed Wing Unmanned Aerial Vehicles

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A Proposal for a Parameterized Circulating Vector Field Guidance for Fixed Wing Unmanned Aerial Vehicles

by

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Abstract

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A Proposal for a Parameterized Circulating Vector Field Guidance for Fixed Wing Unmanned Aerial Vehicles (20 pp.)

Directors of Thesis: Dr. Jay Wilhelm and Coadvisor's Full Name

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Acknowledgments

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1 INTRODUCTION

Unmanned Aerial Vehicles (UAVs) can be used for a multitude of complex tasks such as surveillance, reconnaissance, aerial photography, delivery, and for defense. Accomplishing these tasks require robust and fast execution of three distinct subsystems consisting of navigation, guidance, and control.

1.1 Motivation and Problem Statement

1.2 Methods Overview

1.3 Phases

1.4 Summary of Objectives

- Develop a parameterized circulation method that eliminates the singularity and guides a UAV around an obstacle and to a target. The parametrized circulation term $f(heading, closingvelocity, position, turnrate)$ and would be determined by minimizing a cost.

- Simulate and compare the parametrized circulation with a non parametrized VF guidance for circular and elliptical obstacles

- Emulate fixed wing algorithm with a ground robot to validate simulation results and demonstrate real time VF guidance is achievable with parametrized circulation modification

2 Literature Review

2.1 Unmanned Aerial Vehicles

In literature, UAVs generally occupy one of two categories consisting of fixed wing aircraft and multi-rotor aircraft. Fixed wing aircraft can carry a large payload and are ideal for long endurance missions, whereas multi-rotor aircraft are used when hovering or high maneuverability is desired. Both categories of vehicles require navigation, guidance, and control to maintain flight and accomplish their task. These processes are often automated and programmed into flight controllers that are placed on-board the aircraft itself.

- Tasks (path following, waypoint navigation, loitering)

2.1.1 Flight Mechanics

- Lift - Thrust - Drag

- Kinematics

- Dubins equations of motion

- Dynamics

- Need more literature

- Forward velocity constraints, turn rate constraints

- Transition could be the autopilot ensures that the vehicle does not violate these constraints or attempt to

- Autopilot (combindation of hardware and software, takes mission objectives and produces necessary actuator output)

2.2 Navigation

Before commanding a vehicle to a given task it is paramount that the location of a vehicle with respect to some reference point is known. Measuring, filtering, and estimating the location of a vehicle generally falls under the study of navigation.

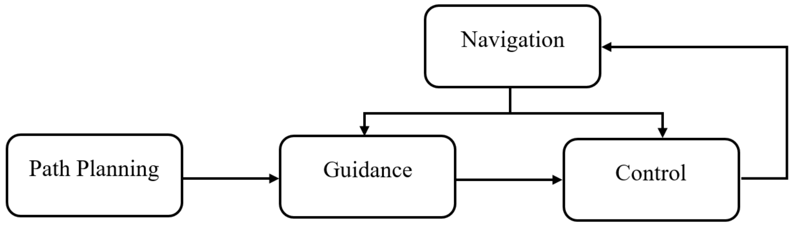

Figure 2.1: Navigation Guidance and Control Flowchart

Commanding a vehicles heading and general operation is provided by a guidance system. Maintaining vehicle stability and reducing any errors is the responsibility of a control system.

Sensor packages containing GPS receivers, barometers, and compasses measure the location and heading of a vehicle. Data is always subject to uncertainty caused by process and measurement noise. Filtering measurements with Kalman filters produce estimates that more accurately represent the location and heading.

2.3 Guidance and Control

Traditional guidance and control are considered separate and independent systems that only exchange the most basic information. High level guidance provides the control system with a commanded heading and velocity to guide the UAV to a path or waypoint designed by the path planner. Low level control accepts the guidance and attempts to drive the state error to zero while maintaining vehicle stability. As more complicated tasks are assigned to UAVs, such as converge and follow a moving path [OAE16] either the guidance or control will become more complicated. The line between guidance and control is starting to become less tangible as the responsibilities of the guidance system becomes more intertwined with control systems.

One notable field of study in robotic guidance is that of vector fields. Each point in the operational space of the robot is assigned a vector of *n*-dimensions that can represent velocity, acceleration, or any arbitrary state. Vector fields have been shown to be an effective way to guide a UAV to a path and does so with less error and control effort than non-linear guidance, linear quadratic regulator, carrot chasing, and pure pursuit line of sight methods [SSS14]. There are many ways to build a vector field including potential Lagrangian functions [Kha86], Lyapunov navigation functions [EK02][Fre] [Nel05], and integral curves by intersection of surfaces [GPMP09] [GPM+10].

2.3.1 Potential Field

Potential field is a real-time robotic manipulator algorithm that distributes the task of goal seeking and obstacle avoidance among multiple layers of control [Kha86]. The robot's workspace is represented as a gradient potential of attractive and repulsive artificial forces that drive the robot to a desired state. Goals are represented as an attractive force while obstacles provide a repulsive force. The potential field is constructed by modeling the robots motion in terms of Lagrangian mechanics shown in Equation 2.1. The Lagrangian is defined as the difference in kinetic energy $T(x, \dot{x})$ and potential energy $U(x)$ in a system. The goal of the system imparts a potential U_{xd} while obstacles impart a repulsive potential U_o.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = F \tag{2.1}$$

$$L(x, \dot{x}) = T(x, \dot{x}) - U(x) \tag{2.2}$$

$$U_{art}(x) = U_{xd} + U_o(x) \tag{2.3}$$

- Potential field (what is it) (edge of bowl, marble, goal, obstacles)
- Calculation time

  - Long time to calculate
  - Environment changes, entire field has to be regenerated
  - Improvements could be made with better computing methods . . .

- Local minimums
  - Local minimums are a significant area of study in potential field
  - Examples of how the problem is being addressed
  - Common issue across the board - No clear solution in sight
  - As missions become more complex, the problem only worsens

2.3.2 Vector Field

- First appearance of vector field (Histogram approach) [Koren 1989] (read before typing it out)
- Experiments with sonar sensor robots [Koren and B 1991]
- [BK90] Improvements on previous vector field histogram
- Ground robot
- Later work provided improvements
- Limitations, size of cells, instability and oscillations
- Problems with VF, used as a general path planner with another local path planner on top
- (transition)
- First instance of generating a field for converging onto paths made of straight line and circular segments (Nelson, Barber, 2006)

- Field construction of Nelson and Barber (More reading)
- Added benefit of VF is adding component to counteract wind
- Cooperative Standoff Tracking of Uncertain moving targets (2007, Frew)
- VF usefulness extended to loitering about an uncertain target
- Lyapunov vector field generation for a circular loiter
- Linear transformation applied to stretch the field into an ellipse shape

2.4 Simulation and Emulation

- As new features and improvements are made to the autopilot software, it is often useful to test the performance of the software in a virtual environment. The process of simulating the autopilot software is called Software in the Loop (SITL).

An additional testbed for new navigation, guidance, and control algorithms is the method of emulation. Emulation is the process of mimicking the kinematics of a complex dynamic system on a simplified system. Fixed wing UAV emulation has been observed in [LDN+14], [RMSB07], and [LEBD16].

2.5 Literature Review Summary

3 METHODOLOGY

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Appendix: An Appendix

A.1 A Section in the Appendix