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

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Garrett S. Clem

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by

GARRETT S. CLEM

has been approved for

the Department of Mechanical Engineering

and the Russ College of Engineering and Technology by

Jay P. Wilhelm

Assistant Professor of Mechanical Engineering

Dennis Irwin

Dean, Russ College of Engineering and Technology

# Abstract

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ABSTRACT

*DED*

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# Table of Contents

Page

Abstract . . . 3

Dedication . . . 4

Acknowledgments . . . 5

List of Tables . . . 8

List of Figures . . . 9

List of Symbols . . . 10

List of Acronyms . . . 11

1 Introduction . . . 12
  1.1 Motivation and Problem Statement . . . 12
  1.2 Methods Overview . . . 13
  1.3 Phase I . . . 13
  1.4 Phase II . . . 13
  1.5 Phase III . . . 13
  1.6 Summary of Phases . . . 14

2 Literature Review . . . 15
  2.1 Introduction to Literature Review . . . 15
  2.2 Fixed Wing Unmanned Aerial Vehicle . . . 15
    2.2.1 Introduction to Fixed Wing UAV . . . 15
    2.2.2 Modeling . . . 15
    2.2.3 Autopilot and Ground Station . . . 15
  2.3 Navigation, Guidance and Control . . . 15
    2.3.1 Introduction to NGC . . . 15
    2.3.2 Navigation . . . 15
    2.3.3 Guidance and Control . . . 15
    2.3.4 Potential Field . . . 15
    2.3.5 Gradient Vector Field . . . 15
  2.4 Vector Field Guidance . . . 15
    2.4.1 Histogram Vector Field . . . 15
    2.4.2 Lyapunov Vector Field . . . 16
  2.5 Literature Review Summary . . . 17

References . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18

# List of Tables

Table Page

# LIST OF FIGURES

Figure Page

# List of Symbols

$a$ Previous or Initial Axial Induction Factor (-)

# List of Acronyms

AoA Angle of Attack

# 1 Introduction

## 1.1 Motivation and Problem Statement

Fixed wing Unmanned Aerial Vehicles are used for long endurance missions such as surveillance that would fatigue pilots or put them in harms way [1]. Missions are typically built using waypoiont navigation and loitering executed by path following [2]. Obstacles are not always known during path planning and once discovered, a new path must be generated. Planning obstacle free and flyable paths takes time and may be impossible to relay to a UAV if communication is not reliable. Guidance that follows mission paths while avoiding obstacles without the need for constant communication with a ground station may be beneficial. Gradient Vector Fields (GVF) produce heading guidance at any point in space by summing together convergence and circulation field components. Each component uses a static scalar weight. Obstacles have been represented as separate repulsive GVFs that are later summed to the path following GVF [Wilhelm, Wambold, Clem]. Static GVF weights do not consider the state of the UAV resulting in sub-optimal guidance. Modifying the GVF convergence and circulation weights to be functions of common UAV states may generate an optimal guidance. **The proposed research seeks to determine GVF weighting functions that construct optimal obstacle avoidance.**

## 1.2 Methods Overview

The proposed research will be conducted in three phases where singularities will be demonstrated, weighting functions will be investigated, and a developed GVF will be validated on a ground robot simulating a UAV. Phases I and II will be conducted in a simulation environment that combines mission paths and obstacles into a single GVF. Phase III will be conducted with a ground robot simulating a UAV guided by the modified GVF in real-time. Dubins fixed wing constraints will be imposed in simulations and experiments.

## 1.3 Phase I

**Recreate vector fields for circular and elliptical obstacles and demonstrate singularities.** A simulation environment will be built that generates GVFs consisting of mission paths and obstacles. Circular and elliptical obstacles will be investigated and the resulting singularities will be characterized. Static weights will be used and the performance of the guidance measured in distance traveled and time of flight.

## 1.4 Phase II

**Investigate GVF weighting functions that influence obstacle avoidance.** UAV closing rate, position, and range will be used to develop dynamic GVF weights for convergence and circulation. The modified GVF will be compared against a static and strictly repulsive GVF. Distance traveled and time of flight will be used to compare the modified GVF to the unmodified GVF.

## 1.5 Phase III

**Validate modified GVF model with ground robot experiments.** The modified GVF developed in Phase II will be implemented on a differential drive ground robot simulating a fixed wing UAV. Guidance to guide the robot to a path while avoiding static obstacles will be demonstrated.

## 1.6 Summary of Phases

Each phases consists of a **goal** that will be accomplished by executing *objectives*. Completion of all objectives and phases will result in the final deliverable.

**Phase I:** Demonstrate Gradient Vector Field Singularities

1. *Build a GVF simulation environment*
2. *Derive GVF for circular and elliptical obstacles*
3. *Identify path and obstacles where singularities are produced*

**Phase II:** Investigate GVF weighting functions that influence obstacle avoidance

1. *Formulate circulation and convergence weights as functions of UAV state*
2. *Determine combination of GVF weights that produces optimal guidance in simulation*

**Phase III:** Validate modified GVF model with ground robot experiments

1. *Build differential drive robot*
2. *Build robotic framework to take guidance commands*
3. *Repeat simulations performed in Phase II on ground robot*

**Deliverable:** Modified GVF optimal guidance for path following and static obstacle avoidance.

# 2 Literature Review

## 2.1 Introduction to Literature Review

## 2.2 Fixed Wing Unmanned Aerial Vehicle

### 2.2.1 Introduction to Fixed Wing UAV

### 2.2.2 Modeling

### 2.2.3 Autopilot and Ground Station

## 2.3 Navigation, Guidance and Control

### 2.3.1 Introduction to NGC

### 2.3.2 Navigation

### 2.3.3 Guidance and Control

### 2.3.4 Potential Field

### 2.3.5 Gradient Vector Field

## 2.4 Vector Field Guidance

- Discussion on vector fields (what, uses, types....)
- Vector field description (Generation of vectors at any point in space)
- VF benefits (Guidance to established control system, continuous guidance, works well for disturbance rejection (wind))
- Conclusion

### 2.4.1 Histogram Vector Field

- Guidance method discretized space

- Obstacles detected and a confidence integer assigned to active cell
- Goal applied attractive force
- Obstacles applied repulsive force
- Similar to PF in that ”artificial forces” are applied, however they are more guidance than actual states
- Problems with HVF (Discretization, fields point away from obstacles only, no parameters to guide around)
- Although no disturbances were modeled, for a UAV they could conceivably be added to the system
- Moving target not explored, only static case (conceivably could be extended to moving target)

### 2.4.2 Lyapunov Vector Field

- VF in literature have guided/followed paths that have been pre-defined
- Several
- Vector field histogram (Repulsive objects, cells, goal, discretization)
- Lyapunov
  - Path following with primitives, activate and deactivate fields, no summing together to prevent singularities
  - Nelsons method of primitives extended to curved paths
  - Tracking uncertain targets (uncertainty used for coordinate transformation to alter field)

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- Gradeint vector field
  - Intersection of surfaces, zero sets represent path
  - n-dimensions for any shapes (unlike some Lyapunov made of primitives)
  - Guaranteed vectors converge to path
  - Equations (convergence, circulation, tv)
  - Obstacles and paths are static, TV term is not considered
  - Examples of components FIGURES: (circulation,convergence,total)
  - Normalization of vectors gives each component equal influence on the total vector
  - After normalization a scalar weight influences how much influence each component has
  - Weights do not effect the guarantee of convergence (non zero and positive)
  - FIGURE: With normalization, without normalization (SIDE BY SIDE)
  - Dubins vehicle example of saturation
  - Static GVF weights do not consider state of the vehicle and provide sub-optimal guidance for obstacle avoidance
  - Dynamic GVF weights as a function of vehicle state may provide an optimal guidance for obstacle avoidance

## 2.5 Literature Review Summary

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