Week 8 Report (Jan 9th - 15th, 2023)

Junwoo Hwang

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Abstract

In Week 8, I focused on formulating various Velocity ramp-in functions based on Track Error, especially on 'Jerk limited trajectory (not completed)', 'TJ NPFG with bearing feasibility stripped', etc.

Important conclusions were:

1. Track error boundary shouldn't be normalized when plotting velocity ramp-in curves
2. Defining different velocity constraints is the key to defining a clear path following velocity reference

Nomenclature

V_{max} Maximum Speed vehicle can achieve

V_{min} Minimum Speed Vehicle can achieve

V_{nom} Nominal Speed Vehicle can achieve (cruise speed for Fixed Wing)

V_{path} Desired speed on path

$V_{approach}$ Desired approaching speed orthogonal to path (outside track error boundary)

$V_{ref}^{\perp}$ Orthogonal component to path, of the reference (target) velocity

$V_{ref}^{\parallel}$ Parallel component to path, of the reference (target) velocity

e Cross track error distance to the path

e_b Track error boundary

$\hat{t_p}$ Unit tangent vector of the path segment

It would be important to set the definition for variables used in this report and future ones clearly. Refer to Figure 1 for visual representation of these variables.

1 Discussion with TJ

Me, Jay, David, and Thomas had a discussion on January 13th on the overall status of the project and what we should try, since I am deriving the formulation from Thomas' paper. The meeting note can be found here: TJ discussion Notes.

1.1 Optimization Criteria

The trajectory can be either time-optimized or jerk-optimized. For this, Jay mentioned that **time optimal trajectory would be sufficient**.

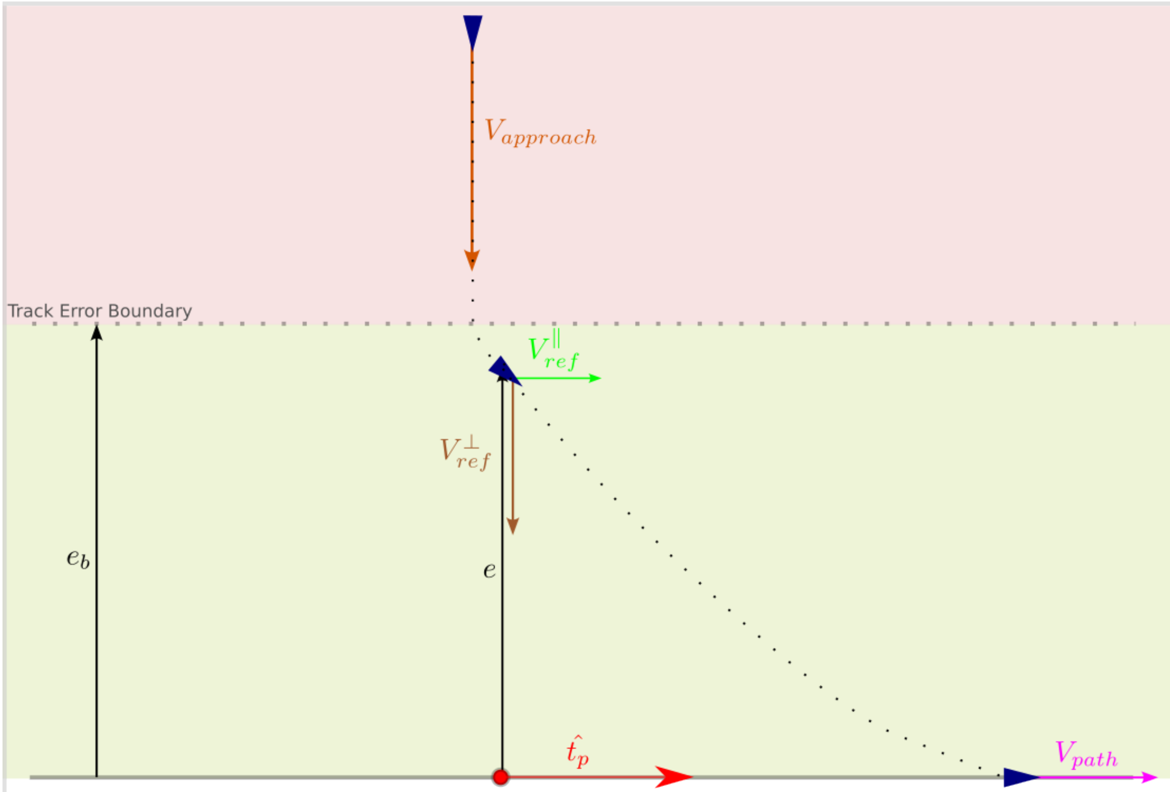

Figure 1: Typical path following scenario nomenclature

1.2 How Vehicle state affects the guidance

In original formulation, the track error boundary is calculated proportional to vehicle's real time ground speed state. In theory, we want to decouple the high level guidance law from vehicle's current state (which in an extreme form will resemble the Model Predictive Control techniques).

Therefore, defining just the track error boundary on vehicle state would be acceptable, given that all the other states of the vehicle doesn't interfere with the high level guidance.

1.3 High level vs Low level controller dependency

We can imagine cases where vehicle is moving in a completely opposite/wrong direction from the Vector Field formed around the path, however **we decided to *trust* that the lower level control** (attitude, velocity, acceleration) would then be able to saturate these errors to eventually converge to path.

We *could* form a Vector Field that takes into account current course angle of the vehicle as well as other information as well, but this would result in entangled relationship between the high level guidance and low level control, which we want to avoid.

1.4 Jerk limited trajectory

Although some effort was put in creating a truly jerk/acceleration limited trajectory (and thus velocity curves), it was concluded that **first having a unified formulation that can work for both multicopter and fixed wing should be a priority.**

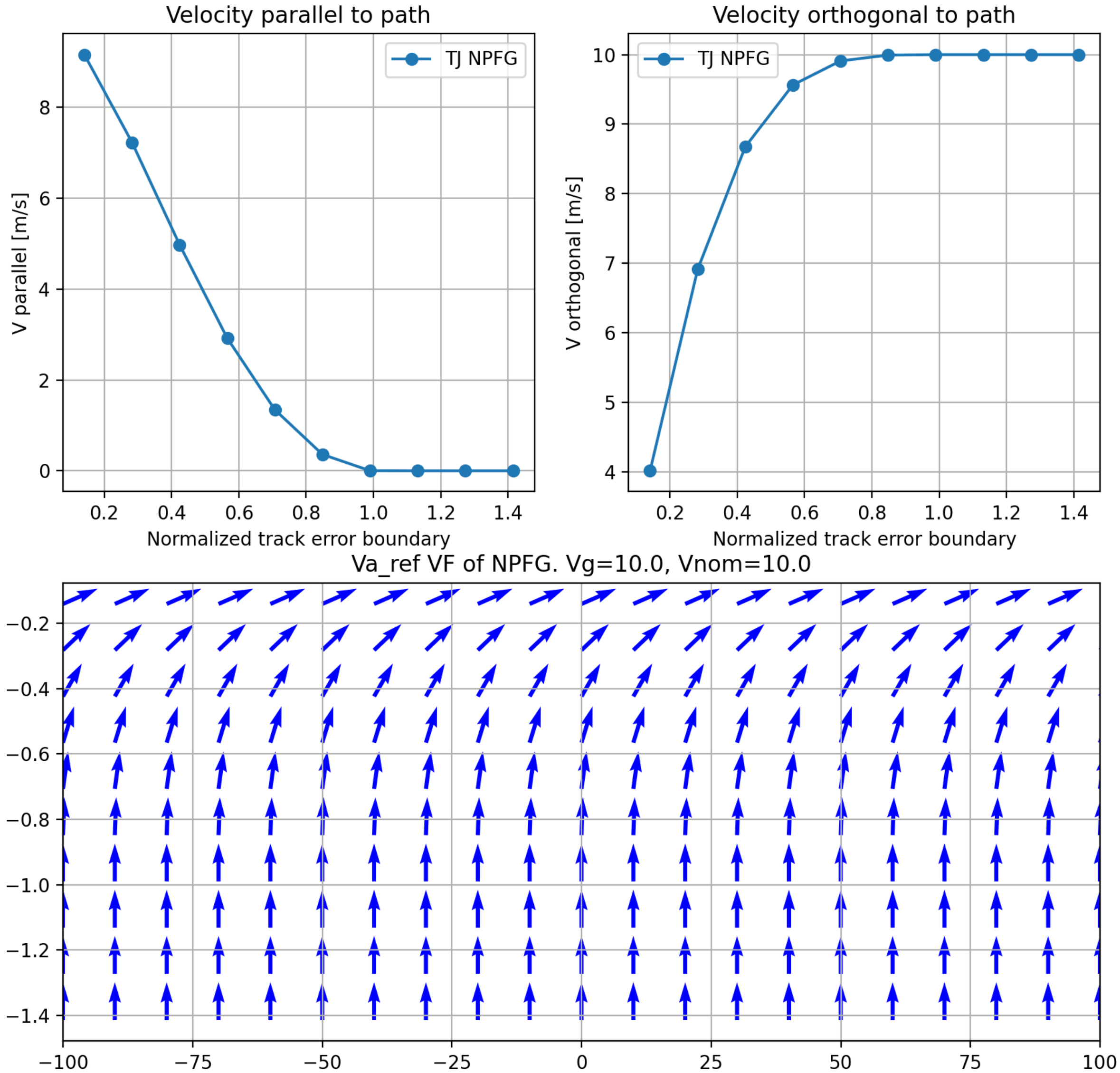

Figure 2: Velocity Curves of native TJ NPFG algorithm

2 Cartesian Velocity Curve Visualization

2.1 TJ's NPFG Velocity Curve

As a starting point, TJ's NPFG Velocity Curve was drawn. Where an expected ramp-in/out of the V_{nom} was observed.

2.2 Modified TJ's NPFG with bearing feasibility stripped

As noted in the Week 4 Report, TJ's NPFG breaks down when V_{nom} approaches a low enough speed that interferes with the bearing feasibility function (around 1.5 m/s).
Therefore, a new formulation was made where the whole bearing feasibility section was removed. It basically **substitutes the bearing feasibility values to 1.0, which means whatever our velocity reference vector is (the bearing of it), it is achievable.**

Notes

- Since TJ's NPFG has a dependency on vehicle's ground speed (V_{gnd}) for calculating e_b (track

Parameter	Value
V_{nom}	0 m/s
V_{gnd}	1 m/s
V_{tk}	5 m/s

Table 1: Simulated Environment Conditions

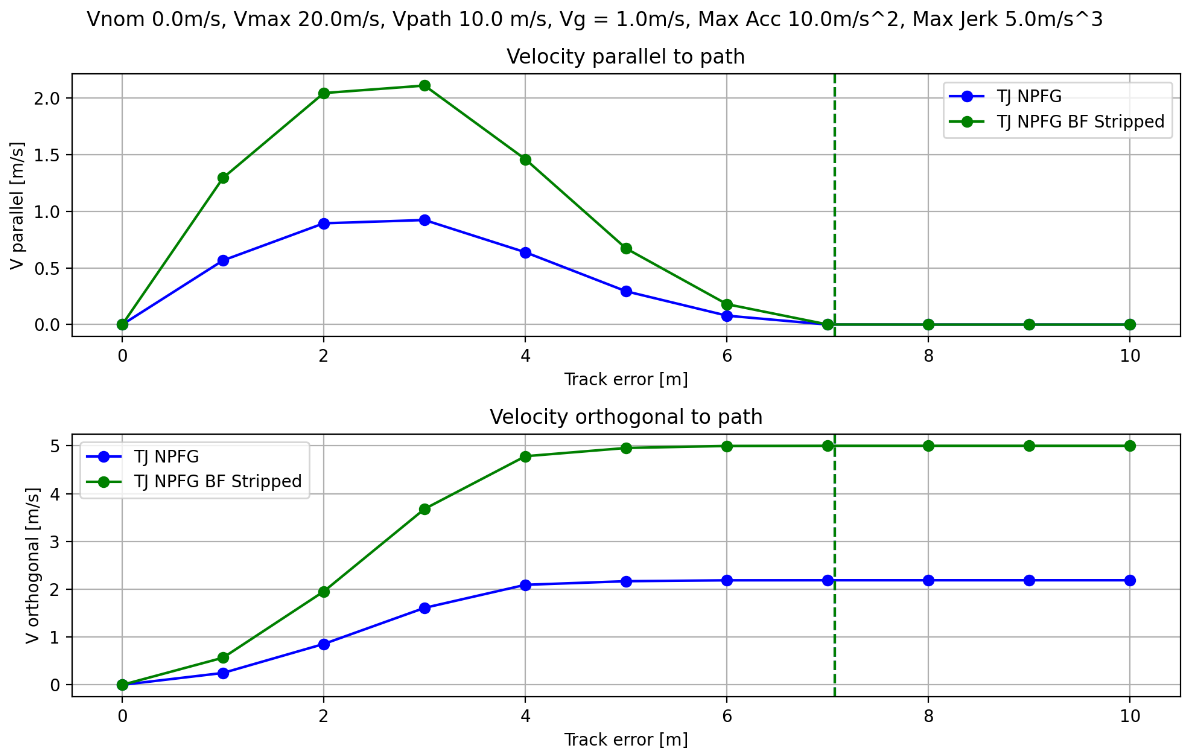

Figure 3: Velocity Curves of two algorithms under same parameter condition in Table 1

error boundary), we provide the same ground speed of the vehicle to the algorithm throughout different track error ranges.

- The track keeping feature (which is what enables having such velocity curves with V_{nom} value of 0) constant (max speed it can command when out of track error boundary) is denoted as V_{tk}.

And these two algorithms' velocity curves were evaluated: Figure 3

From the Velocity Curve, it is evident that the native TJ's NPFG draws somewhat of a weird curve, as the track keeping velocity (V_{tk}) gets scaled down by it's bearing feasibility, as well as the look-ahead-angle turning, and scaling down of the track keeping velocity as the normalized track error approaches 0.

For the bearing feasibility stripped formulation, it shows a *true, non-bearing feasibility scaled* velocity vector, which is a result of scaling down V_{tk} based on normalized track error, and turning it by the Look-ahead angle.

2.3 Analysis

By omitting the bearing feasibility, ability to fully utilize the track keeping speed was restored. However, the following limitations exist due to the fixed-wing optimization of TJ's NPFG:

1. V_{path} isn't considered at all, since for fixed-wings, they are equal to V_{nom}

2. e_b is determined purely by V_{gnd}. But we could also have a fixed barrier based on $V_approach$ (this concept doesn't exist in TJ NPFG) or V_{nom}

3 Other

My goal for Week 8 report was to write it in LaTeX, which is partly why it got delayed. However, I hope this builds some basis for me to write my thesis in LaTeX!

3.1 About the Project

This report is part of the Unified Path Following Guidance for VTOL Vehicles Bachelor Thesis project (November 2022 - March 2023) at Autonomous Systems Lab, ETH Zurich

Supervisors: Jaeyoung Lim, Florian Achermann, Thomas Stastny, David Rohr, Roland Siegwart, and Hwangnam Kim