Wek 14 & 15 Report - Feb 20, 2023 ~ Mar 5, 2023

Multirotor NPFG Mathematical formulation & Evaluation

In 15_Multirotor_NPFG_Formulation:

1. Formulated different NPFG ground velocity vector field generation methods
2. Came up with quantitative criteria for evaluating the ideal-ness of the vector field
3. Evaluated the criteria for different ground velocity vector fields

Evaluation

Based on the equations given in Formulation section, it is possible to provide definite evaluation values under certain assumptions.

In general, the following assumptions apply:

- $a^{\perp}_{max} = a^{||}_{max} = a_{max}$: Multicopter has uniform acceleration limit in both directions relative to path (for Maximum acceleration formulation)
  - This ensures that $e^{min}_{approach}$ is greater than e^{min}_{path}, so the track error boundary is fixed by V_nom.

Mathematical calculation (V_nom > V_path)

This is the case where we want to achieve a speed lower than V_nom on the path

Algorithm	Time to Convergence [s]	Track error boundary length [m]	Converging path parallel distance [m]	Path Velocity fulfilled [bool]	Speed monotonicity [bool]	Total acceleration RMS [m/s^2]	Maximum acceleration total [m/s^2]	Max acceleration parallel to velocity [m/s^2]	Max acceleration orthogonal to velocity [m/s^2
TJ NPFG Original	~~Source~~	$V_{nom} * t_{const}$	$V_{nom} * t_{const} * 0.18$ Source	False	True	$\frac{V_{nom}}{t_{const}} * 0.8288$ Source	$\frac{V_{nom}}{t_{const}} (\hat{e} = 1)$	0 No longitudinal acceleration	$\frac{V_{nom}}{t_{const}} (\hat{e} = 1)$ Source
TJ NPFG Squashed	~~Source~~	$V_{nom} * t_{const}$	$V_{path} * t_{const} * 0.18$	True	True (Elliptical curve)	Between $\frac{V_{nom}}{t_{const}} * 0.3\ (V_{path} = 0)$ & $\frac{V_{nom}}{t_{const}} * 0.8288$ Source	Between $\frac{V_{nom}}{2t_{const}} (V_{path} = 0)$ $\hat{e} = \frac{1}{\sqrt{2}}$ & $\frac{V_{nom}}{t_{const}} (V_{path} = V_{nom})$	$\frac{V_{nom}}{t_{const}} * 0.385 * (1 - (\frac{V_{path}}{V_{nom}})^2)$ $(\hat{e} = 0.374)$ Source Reaches max when V_path = 0 (max deceleration)	$\frac{V_{path}}{t_{const}} (\hat{e} = 1)$
Maximum acceleration	$\frac{V_{nom}}{a_{max}} * 0.333$ Source	$\frac{[V_{nom}]^2}{2a_{max}}$	$\frac{V_{path}}{2a_{max}} * \infty$ Doesn't converge Source	True	?				

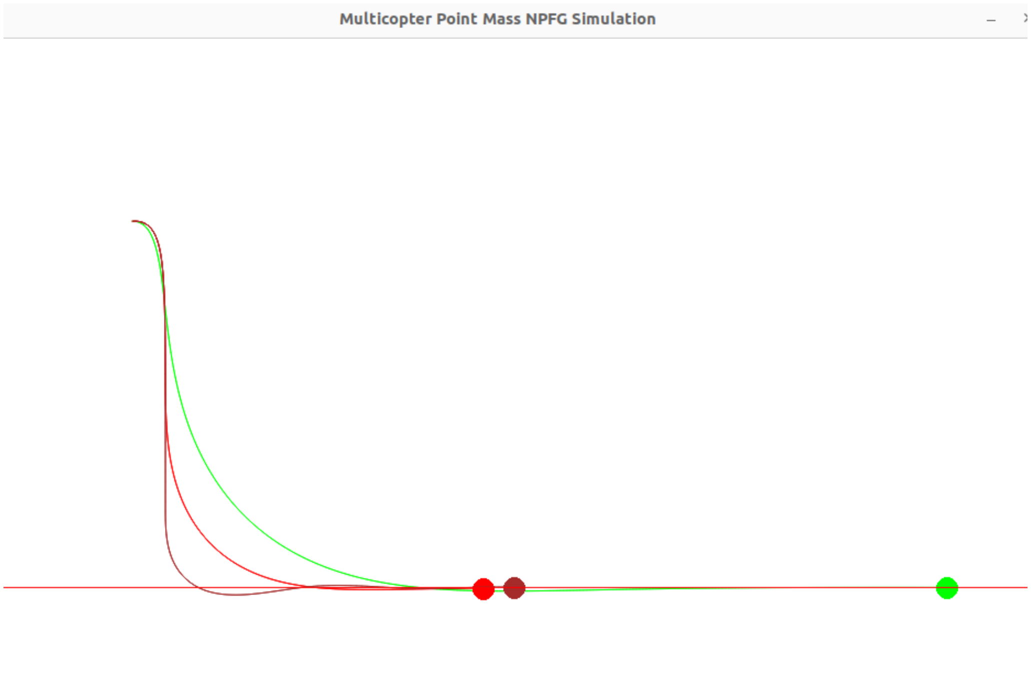
Evaluation result for different algorithms

However, after the meeting on Feb 27, 2023, we concluded:

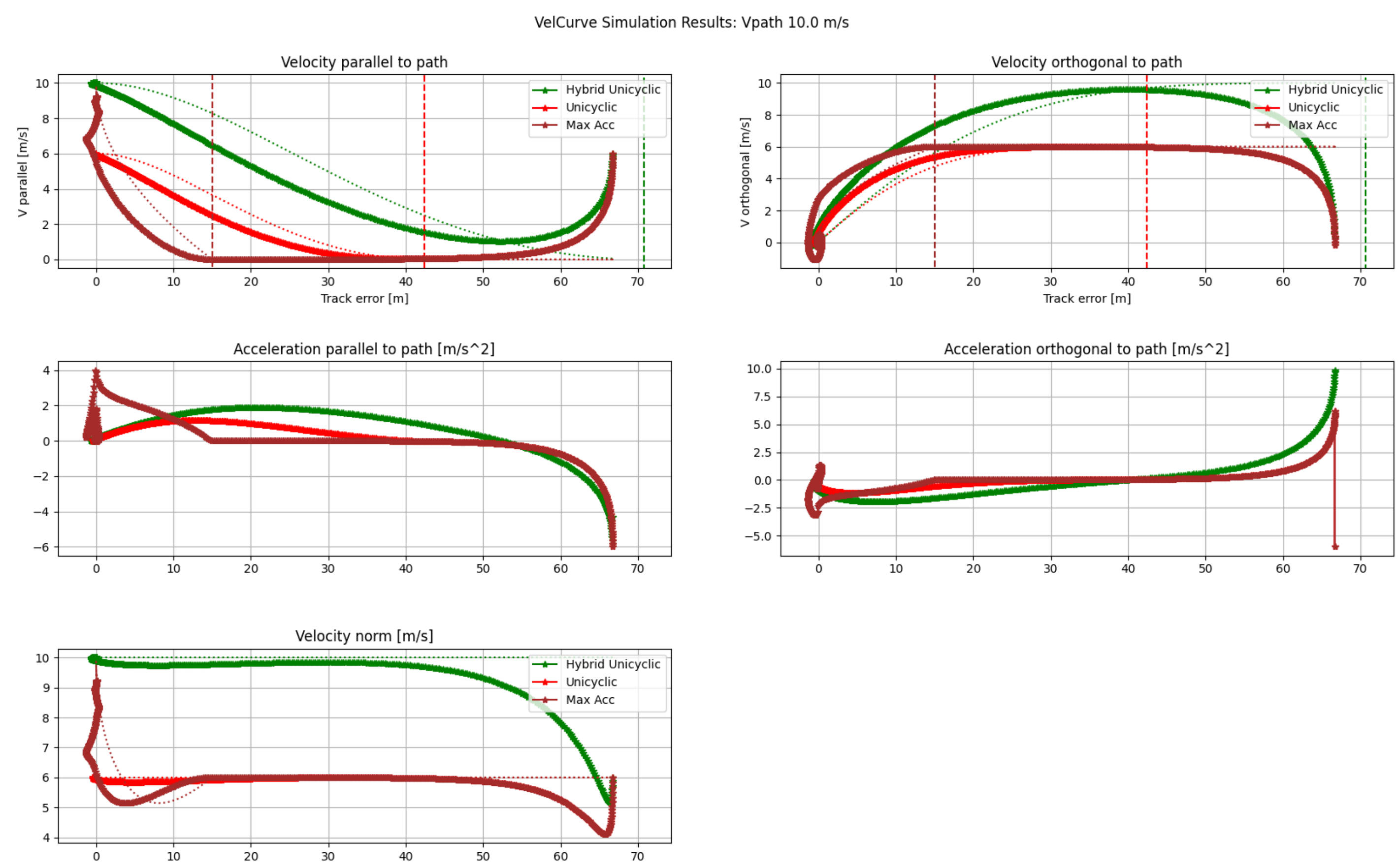
1. **Convergence** to path is mathematically not possible
   a. However we can take the settling time as a reference where it achieves error around the path less than certain fraction of initial error
2. Changing of VF algorithm **names**: 'TJ NPFG' should rather be named 'Unicyclic NPFG'
   a. Since it assumes unicyclic motion, which is the core underlying assumption of the formulation
3. **Varying V_path** problem
   a. For now we should focus on constant V_path case, and then maybe extend to a variable V_path case.
4. **Symbolic** (integration / derivation based) **evaluation** isn't so necessary.
   a. We can just stick to discrete velocity curve based evaluation (with small enough dt, we will get good precision)

Simulation of the VF control in a kinematic multirotor point-mass system

To evaluate the theoretical ground velocity vector field, the velocity curves were applied to a point-mass multirotor simulator with a P-gain position controller (with no acceleration feed-forward):



2D plot of different VF generation algorithm based Multirotor trajectory



Ground velocity curve reference vs actual simulated output graph

Final presentation preparation

As a first step, 15_Final_Evaluation_Ground_Velocity_Vector_Fields presentation was made to showcase the improvement in ground velocity vector field generation.

Analysis on satisfying ‘speed on path’ requirement

	Path velocity **<** Nominal airspeed	Path velocity **>** Nominal airspeed
Original	Ground velocity on path: **Nominal airspeed**	Ground velocity on path: **Nominal airspeed**
Proposed	Ground velocity on path: **Path velocity**	Ground velocity on path: **Path velocity**

Snippet from the presentation

Final presentation

Final presentation will be held on Mar 13, 2023, 10:25am CET.

Final Report

Final report will be submitted by Mar 27, 2023 (2 weeks after the presentation).

TODOs for the 16th week

For the last week of the thesis project, the following TODOs are prepared:

1. Complete the final presentation (the final!!)
2. Pre-presentation on Mar 9, 2023
3. Evaluate improvement over unicyclic NPFG of the new algorithm in kinematic Simulation
4. Evaluate improvement over unicyclic NPFG in mathematical form

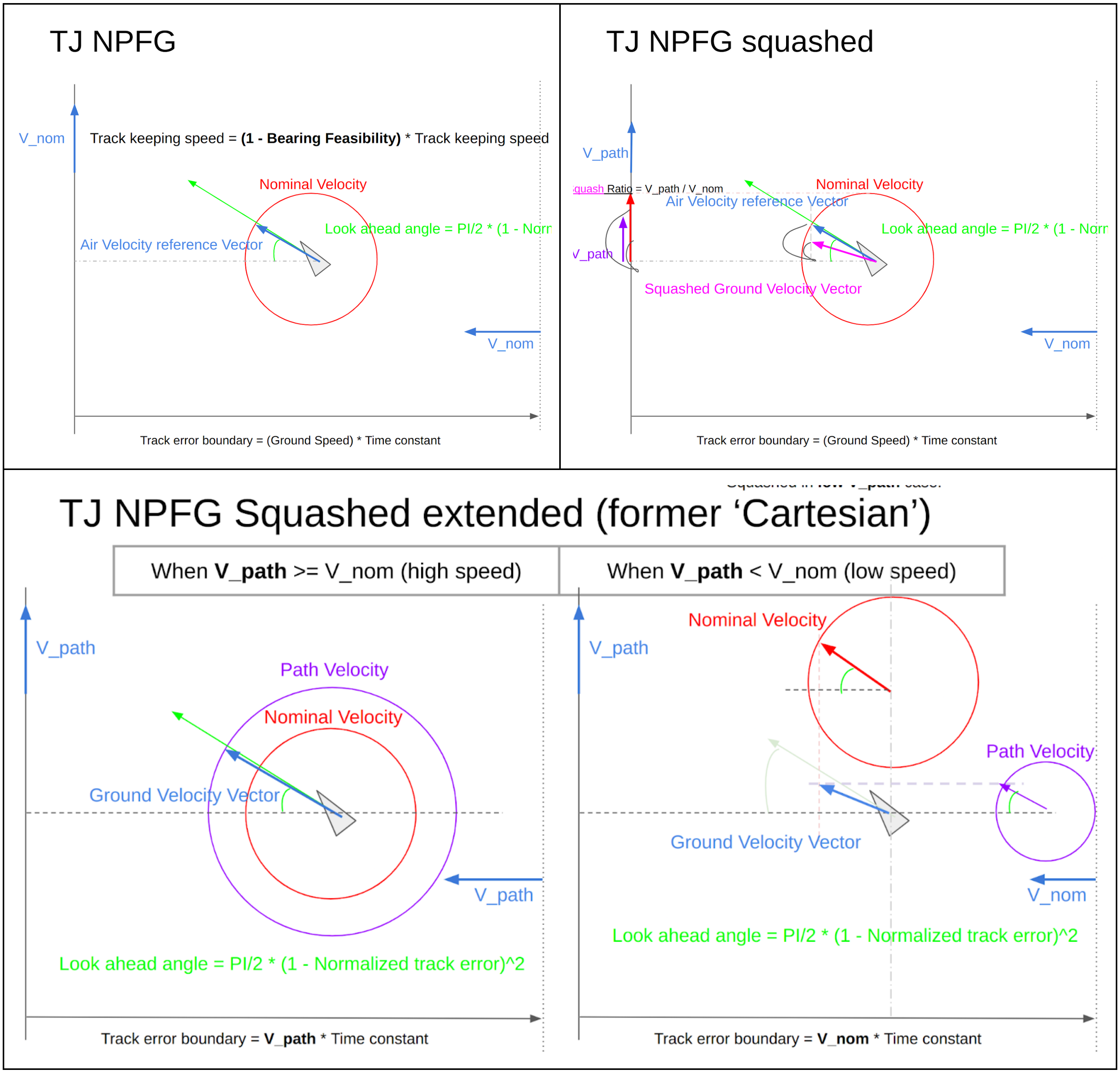
END

Week 13 Report - Feb 13, 2023 ~ Feb 19, 2023

Quantitative Analysis of different velocity curves

Visual representation

In this week, more in-depth study of the different velocity curve formulation method was performed. First, different formulations were drawn:



Analysis Criteria

Then the curves were analyzed in terms of: Acceleration, Course-rate (how fast course direction of the velocity vector changes), Velocity norm (to check monoticity of total speed), path drawn (for intuitive sense).

With the goal of coming up with velocity formulation achieving:

- **Monotomic** velocity norm (either decreasing or increasing) across the track error range
- **Acceleration** required to follow the curve is within the bound (vehicle actuation constraints)
- **Rate of course** over ground (as we are drawing Vector Field as ground velocity) shouldn't be aggressive/discontinuous (as for Fixed-Wing: yaw-rate == sin(banking angle), discontinuous yaw-rate is not feasible!)
- Path over 2D plane around the path should be reasonable

Analysis Result

First, few problems in previous nomenclature / parameters of different algorithms were discovered:

- **Track keeping speed**: Originally from TJ's NPFG formulation for handling excess wind, I concluded that this should NOT be used as the driving factor for Multicopter to return to path, at least in formulation of ground speed vector field **So it is set to 0 now (disabled)**
- **Nominal speed**: Originally we set this to 0 (Multicopter) to test extreme cases. However, as we are using 'cruise speed' for Fxied Wing's Nominal Speed, it **wouldn't make sense to arbitrariliy use 0 for multicopter. Rather, choosing a sane 'cruise' speed** would be more adequate
- **Minimum approach speed**: As nominal speed is never 0 now, the minimum approach speed isn't so relevant (as V_path and V_nom alone has big value to assure vehicle coming back to path in sane time). So it is **set to 0 now (disabled)**

Then the graphs were drawn for the metrics we are interested in.

Please find whole summary in: 14_VelocityCurves_QuantiativeAnalysis & graphs in 14_Quantitative_Analysis_of_Vel_Curves slides.

Further TODOs

Now that the ideal curve is taking shape: "TJ NPFG Squashed Extended", few finishing details are necessary:

1. Handling path with **curvatures**
   a. TJ NPFG dealed with this by altering look-ahead angle even further, but with current formulation the Squashed formulation would provide a parallel velocity component *less than V_path (as it will get rotated further), how do we solve this?
2. **Handling VTOL transitions**
   a. e.g. when approaching from far, how do we decide which velocity vector field should be given? Or should PF algorithm just know about the [0, V_max] range, and throw whatever speed, to which vehicle should transition / semi-transition?)
   b. Even so, how do we handle discrepancy in V_nom for MC / FW? (How do we decide which one to give priority to, in different scenarios?)
3. Considering wind
   a. Now we have rough Ground velocity vector field, but how do we extend this to air-relative frame?
      i. Is this feasible for MC?

END