Path following guidance logic

<<TEMPLATE START>>
Title: Title of paper
Authors: Authors of paper
Link: Link to paper
Summary: Paper summary in one sentence
Key Points:

- Problem Solved: What problem did they try to solve?
- Main Contributions: What were the main contributions?
- Conditions: Under what conditions is the method applicable?
- What can be improved: What could I improve on top of this paper?
- Stylistic comments:
    - **Good**:
    - **Bad**:

Notes:

- More notes

<<TEMPLATE END>>

Hybrid VTOL PF Papers

Title: Incremental nonlinear dynamic inversion based path-following control for a hybrid quad-plane unmanned aerial vehicle
Authors: Li Zhou, et al.
Link: https://onlinelibrary.wiley.com/doi/10.1002/rnc.6503
Summary: INDI controller architecture for achieving path following for both hover & fixed-wing regime flight of the Hybrid Quadplane VTOL
Key Points:

- Problem Solved: Robust controller that can handle both hover & fixed-wing regime behavior of a Hybrid Quad-plane VTOL for **path following**. Better than active disturbance rejection control & PID control.
- Main Contributions: Unified control method that can take the VF Path Following commands and apply it robustly to 2 distinct flight regime of a Hybrid Quad-plane VTOL
- Conditions: Applies to **Hybrid Quad-plane VTOL vehicle type** only
- What can be improved:
    - **MC: Constant speed of 2m/s is assumed**, with no lateral body frame velocity component. Which limits the capability significantly.
    - **Wind isn't considered natively inside the PF algorithm**, and is considered as a 'disturbance' that INDI can handle.
- Stylistic comments:

- **Good**:
- **Bad**:

Notes:

- The Path Following Algorithm itself wasn't the essence of the paper, however it used the **Vector Field method** from "Overview (Quadrotor): A Survey of Path Following Control Strategies for UAVs Focused on Quadrotors" paper.
- Output of the PF algorithm INDI is capable of tracking: Speed, Course over Ground, Height.
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PF Survey Papers

Title: A Survey and Analysis of Algorithms for Fixed-Wing Unmanned Aerial Vehicles
Authors: P.B. Sujit, Srikanth SariPalli, and joão BorgeS SouSa
Link: https://ieeexplore.ieee.org/document/6712082?reload=true
Summary notes: Summary of existing path following algorithms and performance analysis using simulated environment
Key Points:

- Problem Solved: Provide a guideline on how different path following algorithms behave for the UAV Practitioners
- Main Contributions: Path following performance evaluation under a controlled simulation environment
- Conditions: Simulation was done with a 2D-path
- Stylistic comments:
    - Good: Very intuitive diagrams showing the algorithm's internal calculations. Nice diagrams showing different simulated results in an intuitive manner. Lots of nice color schemes to make the paper more 'enjoyable'
    - Bad: Some diagrams were not well made (e.g. angle representations seems hand drawn: Fig 6). No algorithmic formulation diagram was supplied for LQR and Vector-Field method (only vague vectors)

Notes:

- The algorithm formulations were quite confusing. Why do they have to be so complicated? E.g. compared to the TJ NPFG paper, the formulations involve so many symbols (e.g. Vector-Field: 'Algorithm 8')
- Also, **wind estimation wasn't considered at all** (due to assumption that autopilot's computational power isn't enough for it), so the algorithms have no notion of wind.
- **Nice quantitative result comparison. But the 'weight' for the control effort vs path divergence is just not balanced,** and control effort wasn't really taken into account on penalty in my opinion (due to it's order of magnitude)
- PF algorithms are divided into two categories:
    - Geometric methods: Uses **Virtual Target Point to follow**. NLGL, LOS, Vector Field, etc.
    - Control techniques : PID, Backstepping, etc

Title: A Survey of Path Following Control Strategies for UAVs Focused on Quadrotors
Authors: Bartomeu Rubı, et.al
Link: http://link.springer.com/10.1007/s10846-019-01085-z
Summary notes: Selection of 4 (Backstepping, Feedback linearlization, NLGL, Carrot Chasing) PF methods, and evaluating against a spiral-up path with Quadcopter dynamics.

- *Focus on Quadrotor, and not on fixed-wings!*

Key Points:

- Problem Solved: Evaluate 4 major PF schemes on a **quadcopter** dynamics model
- Main Contributions: **Quantitative** evaluation on PF ability of 4 different schemas on a Quadcopter dynamics in a Simulation, with reasonings behind the result
- Conditions:
    - **Wind** interference is limited (randomly- varied, only applying certain 'force' to the bearing)
    - Quadrotor dynamics has a altitude & attitude controller that can 'fairly well' track the target setpoint
- Stylistic comments:
    - Good: Nice **overview** & discussion on necessity of the paper (focus on 'quadrotor', and different PF algorithm schemas)
    - Bad: Evaluation was done only on spiral-up path, which doesn't represent the range of paths a quadrotor would be expected to follow.
        - Wind was limited to affecting vehicle (~1kg mass) with 1 Newtons of force max.

Notes:

- **2D NLGL was extended to 3D NLGL, but with simply adding yaw-setpoint & altitude setpoint & reducing the 2D velocity setpoint vector size**, which doesn't really utilize the full quadrotor dynamics (or does it?). So height is controlled by absolute reference & 2D planer is controlled by velocity reference (like TJ NPFG)

Title: A review of path following control strategies for autonomous robotic vehicles: theory, simulations, and experiments / Unified Submarine
Authors: Nguyen Hung, Francisco Rego, et.al
Link: http://arxiv.org/abs/2204.07319
Summary notes: Overview on existing path-following algorithms, deriving a vehicle-type agnostic formulation and comparing the performances.
Key Points:

- Problem Solved: Instead of assuming specific vehicle type, emphasize a unified common principle & formulate them
- Main Contributions: Open source Matlab / Gazebo simulation environments, formulation in generic terms (vehicle-agnostic)
- Conditions: Only 'constant' external disturbance (e.g. wind) is considered.
- Stylistic comments:
    - Good: Lots of nice diagrams (some are a bit childish? E.g. Fig 2.6, like PPT)
    - Bad: The 'citation' is horrible, it's quite hard to read (e.g. "Gho21", "Map09")

Notes:
- However, **'quantitative' comparison result wasn't delivered in the end.** This leaves the paper tasting a bit blend, as that's what was promised in the beginning.
- Also, it focuses on underwater submarine platform 'medusa' for testing, therefore the simulation isn't really vehicle-type agnostic!

🀄 Vector Field Methods

Title: Vector Field Based Sliding Mode Control of Curved Path Following for Miniature Unmanned Aerial Vehicles in Winds
Authors: Want, et al.
Link: https://link.springer.com/article/10.1007/s11424-018-8006-y
Summary: df
Key Points:
- Problem Solved: What problem did they try to solve?
- Main Contributions: What were the main contributions?
- Conditions: Under what conditions is the method applicable?
- What can be improved: What could I improve on top of this paper?
- Stylistic comments:
  - **Good**:
  - **Bad**:

Notes:
-

Title: Singularity-free Guiding Vector Field for Robot Navigation
Authors: Yao, et.al
Link: http://arxiv.org/abs/2012.01826
Summary: Higher dimensional VF to remove singularity (VF diminishing) problem
Key Points:
- Problem Solved: What problem did they try to solve?
- Main Contributions: Idea of higher dimensional VF without singularity
- Conditions: Under what conditions is the method applicable?
- What can be improved: What could I improve on top of this paper?
- Stylistic comments:
  - **Good**:
  - **Bad**:

Notes:
- Quite rigorous!
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Title: Vector Field Based Path Following for UAVs using Incremental Nonlinear Dynamic Inversion
Authors: Sharma
Link: Link to paper

Summary: VF based PF for Multirotor with low level controller

Key Points:

- Problem Solved: What problem did they try to solve?
- Main Contributions: What were the main contributions?
- Conditions: Under what conditions is the method applicable?
- What can be improved: What could I improve on top of this paper?
- Stylistic comments:
  - **Good**: Interesting to include journal paper in the thesis as well
  - **Bad**: The spacing / blank pages are a bit too much. Too much quantity!

Notes:

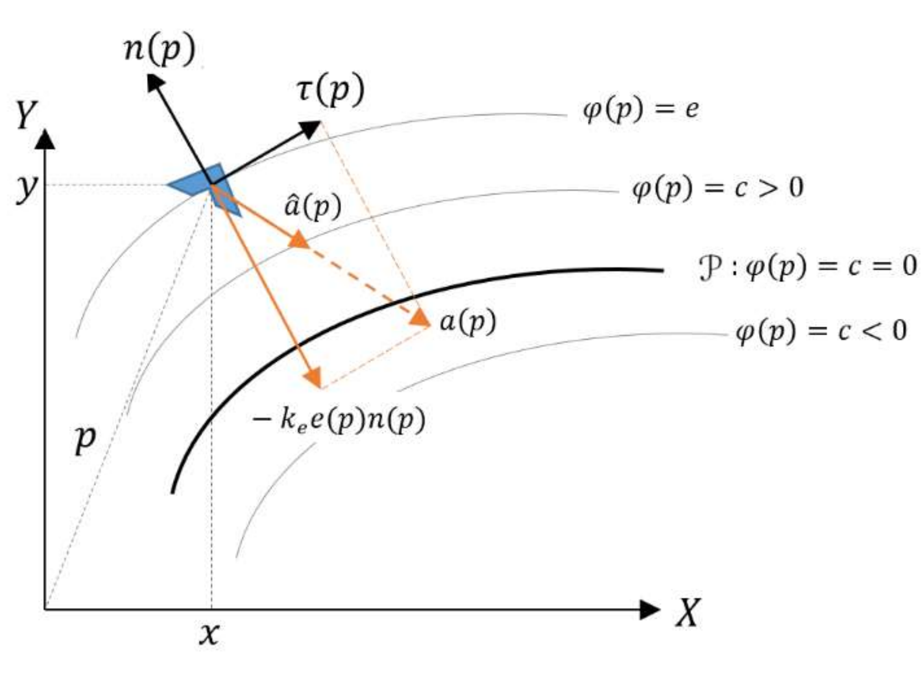
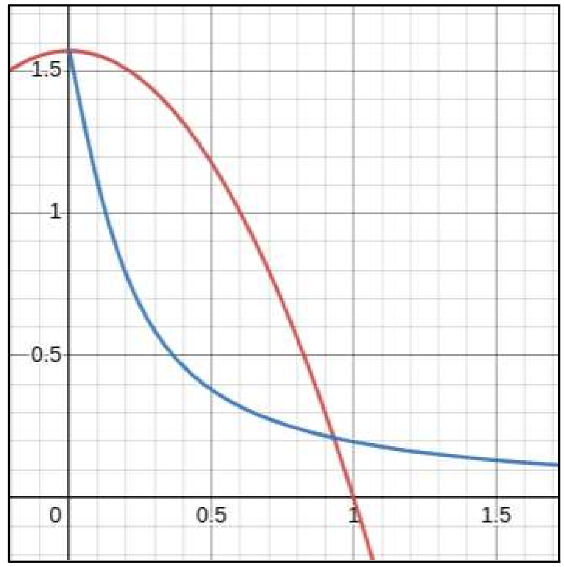
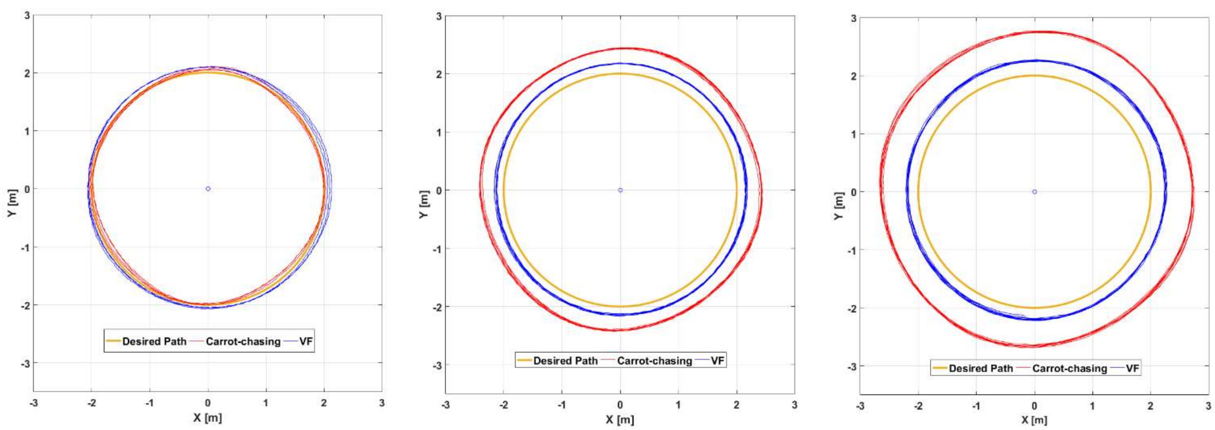
- Doesn't respect the acceleration limit in the VF formulation stage
- 

  Fig. 3: Representation of the UAV and level sets
  - This can be represented in look-ahead angle as:
    - $\theta_{la} = atan(\frac{1}{k_e * e})$
      - Which is: 0 at infinite track error & PI/2 when on-track.
    - **This creates a very different look ahead angle diagram:**

- 

  - [Source]()
- 

(a) Velocity 1 m/s (b) Velocity 2 m/s (c) Velocity 3 m/s

  Fig. 7: Position of the UAV for radius r = 2m
  - Quite horrible constant position error btw
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Title: Vector field path following for small unmanned air vehicles
Authors: Nelson, et.al
Link: http://ieeexplore.ieee.org/document/1657648/
Summary: Classical Vector field based path following for straight line & orbit following
Key Points:

- Problem Solved: VF based path following for UAVs
- Main Contributions: Perhaps just the earliest paper implementing this method?
- Conditions: 2D plane, constant airspeed, no excess wind
- What can be improved: Consideration for maximum lateral acceleration, consideration for wind
- Stylistic comments:

  - **Good**: Table 1 for laying out variables in algorithm was helpful for understanding
  - **Bad**:

Notes:

- It's nice to have 'optimistic' stability analysis (non excess wind), but it's quite simple and only guarantees that vehicle will converge to path without excess wind
- Vector Fields 'switch' when we follow a *different path shape
  - Ah, this is the limitation of geometric classification in VF, which TJ NPFG tackled, making the path more generic (not just straight line & arcs)
- It's interesting that even with wind, tracking error isn't that big, since the bearings were all truly feasible. Control was in the ground 'course'.

Title: On Flying Backwards: Preventing Run-away of Small, Low-speed, Fixed-wing UAVs in Strong Winds 🌬️
Authors: Thomas Stastny and Roland Siegwart
Link: http://arxiv.org/abs/1908.01381
Summary notes: Wind aware path following algorithm that can handle excess wind over the flying speed of the flying wing platform
Notes:

- Problem Solved: Consider excess wind (wind speed > forward flying speed) condition for NPFG path following algorithm
- Main Contributions: Relaxed Buffer zone &
- Conditions: The parameters need to be tuned properly? (E.g. ramp-in constants)
- Stylistic comments:
  - Good
    - Fig 2 was very intuitive & explained the basic assumptions / notations very precisely
    - Fig 4 was very good as well for understanding
    - Fig 8 with real flight experiment data is always cool to include, to show that it actually works in real life 😉
  - Bad
    - It was quite hard to understand Fig 3, as the plot, although showing information concisely, wasn't so intuitive to understand (especially the beta + / - boundaries)

Title: 3D NPFG: Three-Dimensional Nonlinear Differential Geometric Path-Following Guidance Law
Authors: Namhoon Cho∗ and Youdan Kim†
Link: https://arc.aiaa.org/doi/10.2514/1.G001060
Summary notes: Improved NPFG with stability proof for tracking path curvature, on a generic smooth 3D-path
Key Points:

- <u>Problem Solved</u>: Limitation of pre-existing PF with only 2D paths -> 3D

- Main Contributions: Improved NPFG (L- distance based version) that is stability-proofed & simple to implement (Geometric based)
- Conditions:
  - Wind-less environment (Wind isn't considered in Simulation at all)
  - Vehicle is in-line with the path (seems like it's generic assumption (e.g. between Eq 26 & 27)
- What can be improved:
  - Incorporating Wind information
  - Constraint on only applying a 'lateral' acceleration to the inertial velocity
    - Key Question: Is 'lateral acceleration' to inertial velocity always feasible?
    - Even if so, is that the optimal solution for PF?
  - Airspeed setpoint manipulation (vehicle is assumed to move at a somewhat *constant speed)
- Stylistic comments:
  - **Good**: The structure is quite nice
  - **Bad**: Quite theory heavy, could have had few more diagrams for better understanding 🤔

Notes:

- It was super nice to come back to this paper after ~2 months, as now I had more context & overview on PF algorithms, to be able to understand the core concept behind the idea! - Jan 8, 2023
-
- ~~I just found it very hard to understand (although figures were nice), maybe I just need more background information!~~

Other PF Algorithms

~~**Title**: L1 Adaptive Path-Following of Small Fixed-wing Unmanned Aerial Vehicles in Wind~~
~~**Authors**: Toufik Souanef~~
~~**Link:** https://ieeexplore.ieee.org/document/9721593/~~
~~**Summary notes:** Paper summary in one sentence~~
~~**Notes:**~~

- ~~This was a reference for the "P.B. Sujit, et.al; Unmanned Aerial Vehicle Path Following …" paper, regarding 'adaptive control'~~
- ~~Problem Solved: What problem did they try to solve?~~
- ~~Main Contributions: What were the main contributions?~~
- ~~Conditions: Under what conditions is the method applicable?~~
- ~~Stylistic comments: (Optional) Stylistic comments for writing your own papers (e.g. nice way to present this data in a figure, good use of algorithms, bad structure, etc.)~~

Title: L2+, an Improved Line of Sight Guidance Law for UAVs 🎟️
Authors: Renwick Curry1, Mariano Lizarraga, et al
Link: https://ieeexplore.ieee.org/document/6579804
Summary notes: Improved L1 distance manipulation based on ground speed &

Notes:
- Problem Solved: Improve the shortcomings of the pre-existing L1 guidance logic
- What were the main contributions?
- Personal summary - rewrite the abstract for yourself, ideally in a way that you think is simple and precise
- Under what conditions is the method applicable?
- Style
    - Good: Contrast to the original L1 guidance logic's behavior made it intuitive to compare the path following behavior
    - Bad: Wind directions in the figures aren't so clear, would have been nice to have a graphical representation, instead of explaining in the text.

Title: L1: A New Nonlinear Guidance Logic for Trajectory Tracking 🕊️
Authors: Sanghyuk Park,∗ John Deyst,† and Jonathan P. How‡
Link: https://arc.aiaa.org/doi/10.2514/6.2004-4900
Summary notes: Simplistic look-ahead vector based path following guidance using lateral acceleration command | L1 guidance!
Notes:
- What problem did they try to solve?
- Main Contributions: Simple and intuitive guidance logic that is easily applicable for fixed-wing vehicles (lateral acceleration)
    - Analysis of the guidance law's similarity in Circular / Linear trajectory to a pre-existing missile guidance logic & PD controller
- Conditions: No wind?
- Stylistic comments:

VTOL Control

Title: Title of paper
Authors: Authors of paper
Link: Link to paper
Summary notes: Paper summary in one sentence
Notes:
- What problem did they try to solve?
- What were the main contributions?
- Under what conditions is the method applicable?
- (Optional) Stylistic comments for writing your own papers (e.g. nice way to present this data in a figure, good use of algorithms, bad structure, etc.)