Thoughts while making final presentation

I had some thoughts & deeper review / overview on the project's status while making the final presentation: Junwoo Hwang | Final Presentation | BA. I would like to collect them here and discuss after the trial presentation.

Ground Velocity Curve

- **Look-ahead angle** as a function of normalized track error alone **defines the exact ground course profile of approaching the path!**
  - V_approach and V_path only acts as a 'starting' and 'ending' speed while following that course profile, and nothing else!
  - Technically, the same ground course profile can be followed with either: Constant speed, varying speed, etc, that's up to the velocity setpoint
  - When look-ahead angle function is fixed, the **'track error boundary' defines solely the scaling of the whole ground course.**
    - In fact, the **parallel travel along the path until convergence is only dependent on the track error boundary** with a fixed look-ahead angle function. And it scales linearly.
      - Proof: $d_{conv} = -\int_{e_b}^{0} V_g^{||} \cdot \frac{1}{V_g^{\perp}}\, de = e_b \cdot \int_0^1 V_g^{||} \cdot \frac{1}{V_g^{\perp}}\, d\hat{e} = e_b \cdot \int_0^1 tan(\theta_{la}(\hat{e}))\, d\hat{e}$
        - Reference: 15_Multirotor_NPFG_Formulation
  - However the **'convergence time' is indeed dependent in the magnitude of the velocity** following the ground course profile!

Therefore, the ground velocity curve problem breaks down into:
1. Defining look-ahead angle function (Shape of approach)
2. Defining track error boundary (Scale of approach)
3. Defining speed (norm of the velocity) profile (Convergence time & dynamics)

And the step 2 ~ 3 essentially encompasses the choice of V_approach and V_path!

Evaluations

Bringing back the evaluations, we can re-formulate the 3 step process incorporated into metrics like so:

Variables: $\theta_{la}(\hat{e})\ course\ shape,\ e_b\ track\ error\ boundary, V_g(\hat{e})\ speed\ over\ ground\ profile$

Criteria	Description	Evaluation
Time to convergence on a path [s]	Time required by the vehicle to converge to the path when following the ground velocity vector field with no error $$t_{conv} = -\int_{e_b}^{0} \frac{1}{V_g^{\perp}}\, de = e_b \cdot \int_0^1 \frac{1}{V_g(\hat{e}) \cdot cos(\theta_{la}(\hat{e}))}\, d\hat{e}\ (when\ e_b\ is\ constant)$$	Smaller the better
Track error boundary length [m]	e_b	Smaller the better
Converging path parallel distance [m]	Path-parallel distance travelled to converge to path when following ground velocity vector field with no error $$d_{conv} = -\int_{e_b}^{0} V_g^{||} \cdot \frac{1}{V_g^{\perp}}\, de = e_b \cdot \int_0^1 V_g^{||} \cdot \frac{1}{V_g^{\perp}}\, d\hat{e} = e_b \cdot \int_0^1 tan(\theta_{la}(\hat{e}))\, d\hat{e}\ (when\ e_b\ is\ constant)$$	Smaller the better

Velocity on Path fulfilled [bool]	$V_g^{\|\|} = V_{path}\ when\ \hat{e} = 0$	Needs to be True
Speed **monotonicity** [bool]	Whether the magnitude of velocity grows or decreases consistently throughout track error boundary $\{\frac{d}{de}\|\|V_g(e)\|\| \ \geq 0 \mid for\ all\ e \in [0,\ e_b]\}$ Or $\{\frac{d}{de}\|\|V_g(e)\|\| \ \leq 0 \mid for\ all\ e \in [0,\ e_b]\}$	Needs to be True
Total **acceleration RMS** [m/s^2]	Root-Mean-Square value of acceleration $acc_{rms} = \sqrt{-\frac{1}{e_b} \cdot \int_{e_b}^{0}(\|\|\frac{d}{dt}V_g\ (e)\|\|^2)\ de} = \sqrt{\int_0^1(\|\|\frac{d}{dt}V_g\ (\hat{e})\|\|^2)\ d\hat{e}}\ (when\ e_b\ is\ constant)$ $= \sqrt{\int_0^1[\|\|\frac{d}{dt}V_g\ (\hat{e})\|\|^2 + V_g(\hat{e}) \cdot \frac{d}{dt}\theta_{la}(\hat{e})]\ d\hat{e}} = \sqrt{\frac{1}{e_b}\int_0^1[V_g(\hat{e})\ cos(\theta_{la}(\hat{e}))] \cdot [\|\|\frac{d}{d\hat{e}}V_g\ (\hat{e})\|\|^2 + (V_g(\hat{e}) \cdot \frac{d}{d\hat{e}}\theta_{la}(\hat{e}))^2]\ d\hat{e}}$	Smaller the better
Maximum acceleration total [m/s^2]	Maximum total acceleration $acc_{max} = max\{\frac{d}{dt}V_g\ (e) \mid for\ e \in [0,\ e_b]\} = \frac{1}{e_b} \cdot max\{V_g cos(\theta_{la}(\hat{e})) \cdot \sqrt{\|\|\frac{d}{d\hat{e}}V_g\ (\hat{e})\|\|^2 + (V_g(\hat{e}) \cdot \frac{d}{d\hat{e}}\theta_{la}(\hat{e}))^2}\ for\ \hat{e} \in [0,\ 1]\}\ (when\ e_b\ is\ constant$	Smaller the better

Track error boundary scaling with ground speed

- This removes the absolute magnitude dependency (scaling), and keeps the scaling consistent
- HOWEVER, this doesn't apply in high-wind situations where the wind speed affects the ground speed significantly for different course targets!
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Path Following high-level command output

- To unify the control of MC & FW, the following commands are expected:
    - Course over ground
    - Ground speed
- Depending on whether it's a FW or a MC, we can have a different approach to controlling the vehicle to follow that setpoint
    - For FW: COG is maintained, but ground speed will likely not be exactly the same
    - For MC: COG and ground speed is both expected to be followed closely
- However, there's still a problem:
    - What do we do in an intermediate transition state?
        - How should this high-level path following control setpoint morph between MC <-> FW configuration, to create sane setpoints?
    - Lateral acceleration command is only applicable to FW case, and thus the whole control pipeline isn't really *unified
    - **INDI** could help in this case?
        - E.g. https://onlinelibrary.wiley.com/doi/abs/10.1002/rnc.6503