PX4 VTOL Vector Control of a Tail-sitter

Roman Bapst

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Motivation

Why is fixed wing VTOL interesting?
- take-off and land like a helicopter
- fly efficient like fixed wing plane

Requirements
- low mechanical complexity
- suitable for prototyping, testing (small scale, easy repairable)
- high efficiency

Examples
- Transition Robotics’ Quadshot
- BirdsEyeView Aerobotics’ FireFly6
- Canadair CL-84
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Airframe

Our Solution: Caipirinha Tail-sitter

- use conventional wing and upgrade it to VTOL
- weight: 900 g, wingspan: 0.84 m
  ⇒ allows convenient, save testing
- low mechanical complexity (no rotation of body parts necessary)
- non-destructible EPP foam
- autopilot: Pixhawk with PX4 firmware

Challenges

- choice of engines and props is crucial:
  efficiency vs. airflow for control authority
- moment generation using flaps is highly airspeed dependant
- large area for wind to attack during hover
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What are the main challenges?

- three flight phases: hover, transition, horizontal flight
- controller needs to work for all phases \(\Rightarrow\) very difficult
- flap actuation non-linear dependant on airspeed
- relevant airspeed is combination of vehicle airspeed & prop induced airspeed
- aerodynamic forces (lift drag) and moments have large impact on vehicle dynamics
\(\Rightarrow\) need good model for control

**Possible solution: Controller switching**

- run multicopter and fixed wing controller and do switching/blending
- gives good results but not elegant, brute force

\(\Rightarrow\) *want a single controller which can handle all phases*
Better solution: VTOL controller

- use cascaded control strategy (position $\rightarrow$ velocity $\rightarrow$ acceleration)
- compute desired attitude and thrust from desired acceleration
- compensate desired acceleration for aerodynamic forces
- use onboard sensors & aerodynamic data to model forces
- can use approximations e.g. lift cancels gravity in horizontal flight

Advantages

- no controller switching necessary, no phase distinction necessary
- can use most structure from multicopter position/attitude controller
Control

Modelling example: Estimation of total airspeed at flaps

- use simple model of airflow and current measurements to estimate total air velocity behind propeller
- can use estimate to scale attitude controller gains

\[ A_0 = A_1 = A_2 = A \]

\[ v_0 = v_1 = v_2 \]

\[ p_0 = p_2 = p_3 \]

\[ v_3 \]

\[ t \in [s] \]

\[ 0 \quad 20 \quad 40 \quad 60 \quad 80 \quad 100 \quad 120 \quad 140 \quad 160 \quad 180 \]

\[ 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \quad 20 \]

measured airspeed
estimated total airspeed

PX4 VTOL Vector Control of a Tail-sitter: Roman Bapst
Velocity tracking results in horizontal flight

reference: red, actual: blue
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Conclusion & Outlook

Conclusion
- VTOL controller allows elegant control throughout entire flight envelope
- no switching of controllers or flight mode distinction necessary
- but: need a good aerodynamic model $\Rightarrow$ wind tunnel data?
- further testing and development required

Outlook
- fly transitions based on desired velocity trajectory
- find suitable aerodynamic model
- make controller robust to model uncertainties
Thank you for your attention