U.S. ARMY RDECOM

Development of a Hybrid Vehicle Capable of Performing Aggressive Maneuvers with On-board Sensing

ARL 25 YEARS 1992-2017

open campus

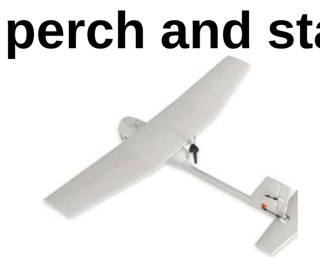
S&T Campaign: Sciences for Maneuver
Tactical Unit Energy Independence

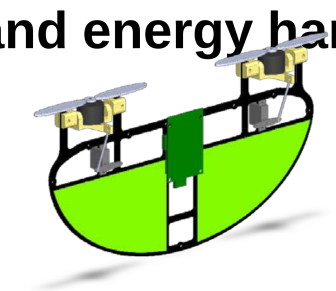
Stephen Nogar
(410) 278-1954
stephen.m.nogar.ctr@mail.mil

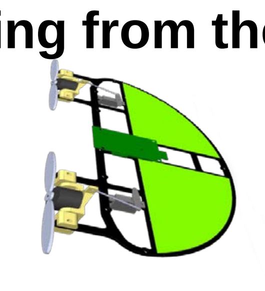
Research Objective

- Small, autonomous micro air vehicles (MAVs) are an important technology that enables improved surveillance and reconnaissance compared to larger vehicles, especially in urban and indoor environments. As the vehicle size decreases (<30 cm), they become increasingly constrained to specialized flight conditions, mission profiles, environments, and sensor packages.
- Design and build a hand held vehicle that is capable of hover, efficient forward flight, and can perform a controlled transition between the two states.
- Develop relevant control algorithms for maintaining stability through transition for the underactuated vehicle.
- Improve on-board sensing capabilities that can enable aggressive maneuvers including perching with a focus on monocular vision techniques that take advantage of small, powerful embedded computers.
- Enable enabling energy efficient behaviors in path planning, gust capture, perch and stare and energy harvesting from the nt


Quadrotor (DJI Phantom)
+ Agile
+ Hover capability
- Limited range and endurance


Fixed wing (Aerovironment Raven)
+ Extended range and endurance
- No hover capability

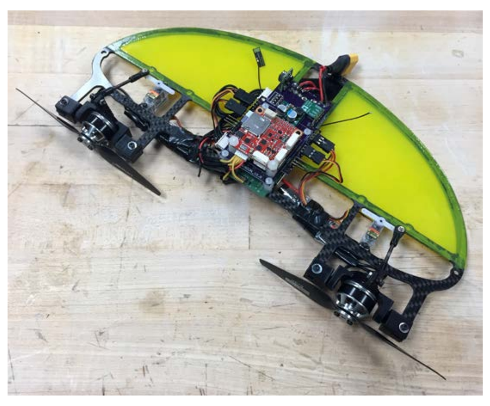

Tilt Rotor (hover)

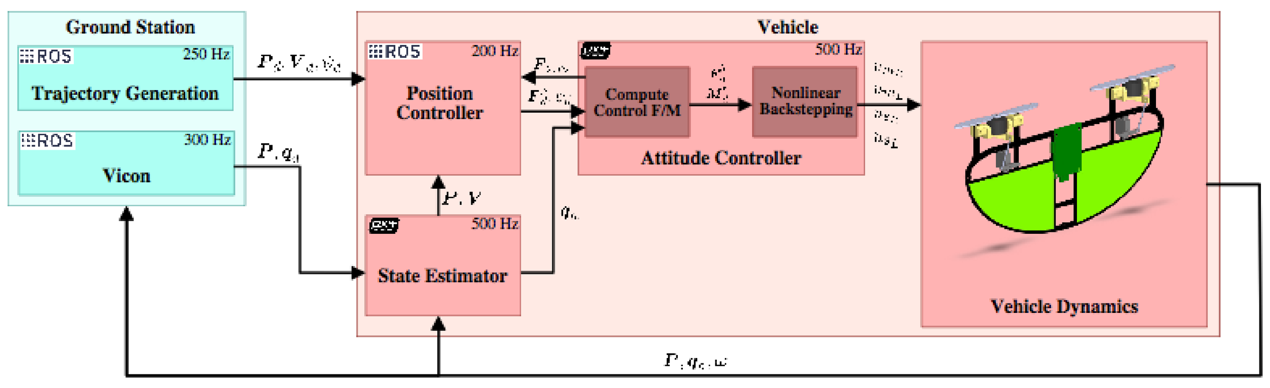

Tilt Rotor (forward flight)

+ Extended range and endurance
+ Hover capability
- Increased control complexity

Technical Approach

- Develop vehicle concept
  - Hybrid vehicle capable of vertical take off and landing (VTOL) using a dual articulated rotor design
  - Hardware based on commercial off the shelf (COTS) components like the Snapdragon Flight to enhance onboard processing capabilities
- Dynamics and control
  - Develop relevant control and dynamics models to enable controlled transition
  - Demonstrate controlled transition using motion capture system
- Perching
  - Develop aggressive flight capabilities and demonstrate perching maneuver using motion capture
  - Achieve autonomous landing in a GPS denied environment using a known target and monocular camera
  - Achieve perching using only on-board sensing for a generic landing target

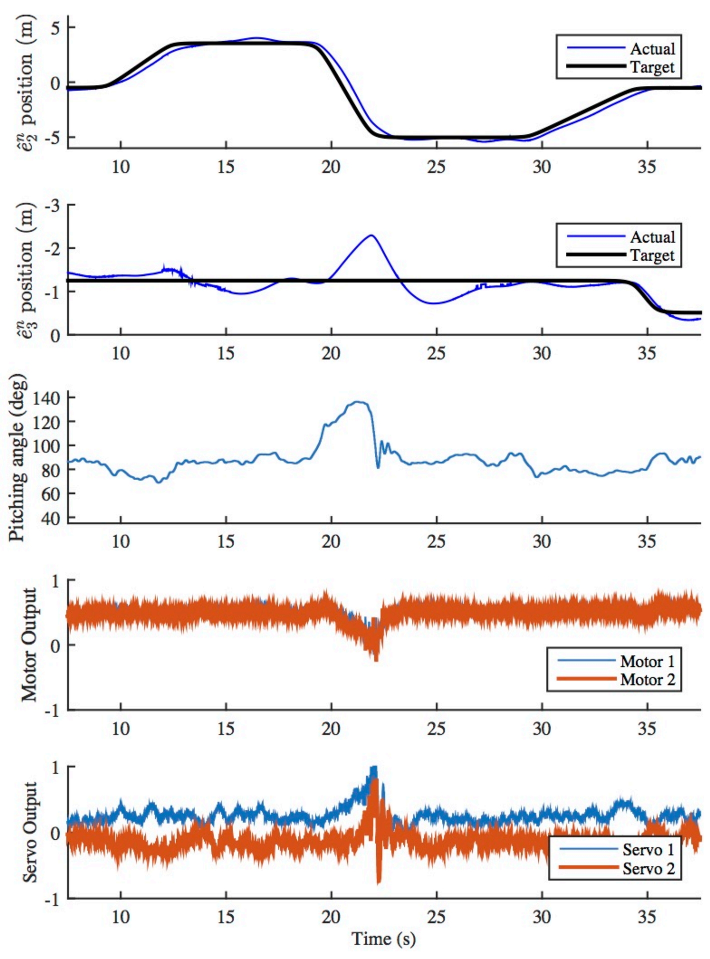

Prototype



Control diagram

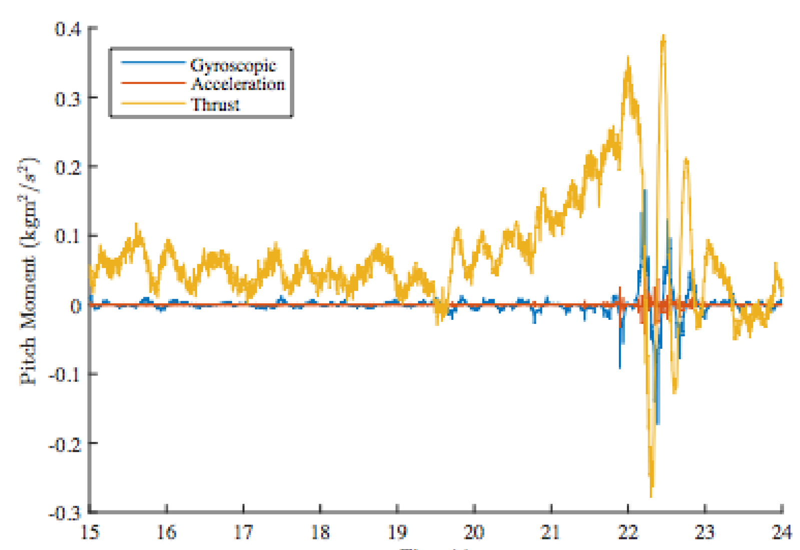
Status and Accomplishments

- Designed and constructed vehicle
- Developed a cascaded, nonlinear backstepping controller that can transition between forward flight and hover
- Cascaded approach
- Uses resolved tilt twist method to determine attitude errors
- Implemented control algorithms on-board using robot operating system (ROS) and PX4 flight controller
- Verified controller performance numerically
- Demonstrated controlled transition using motion capture system
- Confirmed vehicle is approximately twice as efficient in forward flight mode as hover
- Characterized vehicle force and moment capabilities
- Verified adverse pitching moments do not inhibit control and transition
- Demonstrated visual odometry using Snapdragon Flight



Transition results

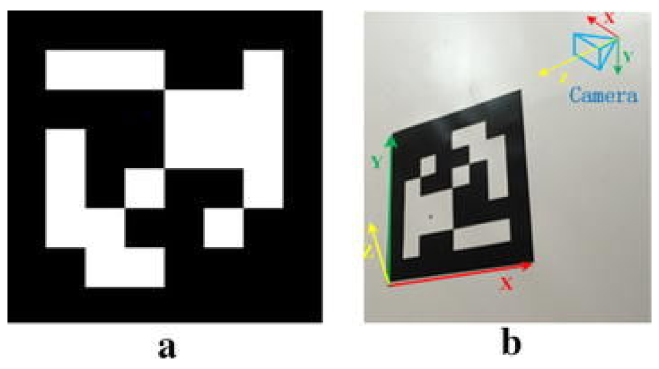

Transition from hover to forward back to hover



Gyroscopic moments during transition

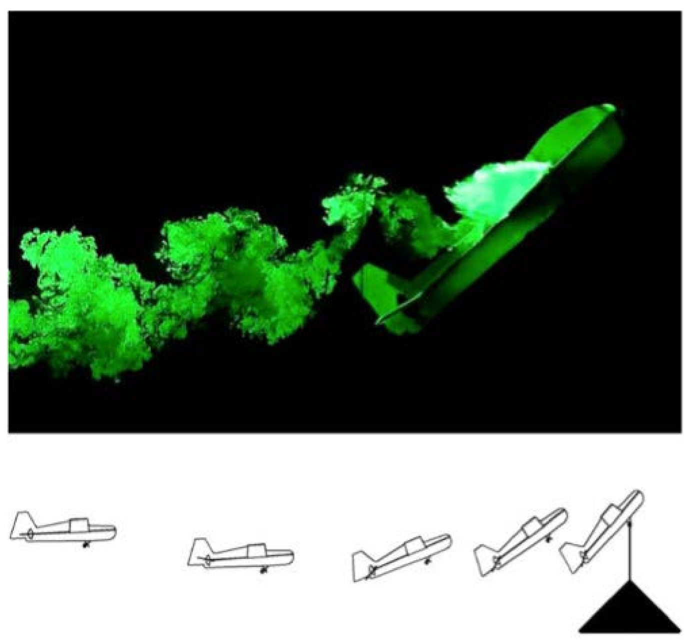
Challenges and Future Research

- Collaborations:
  - University of Pennsylvania - Control and dynamics
  - University of Delaware - Perception
- Facilities:
  - 30'x60' Vicon motion capture area
  - Outdoor areas for flight in APG controlled airspace
  - 3D printing and vehicle prototyping
- Research Areas:
  - Perception:
    - Visual pose estimation: Use a monocular camera to estimate pose relative to a target
    - Visual odometry: Use of monocular camera to aid in state estimation
  - Control and dynamics:
    - Techniques for performing aggressive maneuvers using onboard sensing
    - Machine learning for improved control and dynamics estimation
  - Human-robot teaming
  - Vehicle efficiency:
    - Harnessing energy from the environment
    - Improved vehicle behaviors to minimize energy use



April tag pose estimation
(Tang, Hu, Shen, Ma, Pan, 2016)


Qualcomm Snapdragon Flight


Fixed wing perching
(Moore, Cory, Tedrake 2014)