Guidance and Control of an Autonomous Soaring Vehicle with Flight Test Results

Michael J. Allen
NASA Dryden Flight Research Center
Royal Air Force Visit
May 8, 2007
Background

- Many UAVs have similar mission constraints to birds and sailplanes.
  - Surveillance
  - Point to point flight with minimal energy
  - Increased ground speed
- Birds use atmospheric energy to hunt, forage, and migrate thousands of miles.
- Manned sailplanes rely solely on atmospheric energy
  - 2,000km (1,200mi) maximum distance.
  - Cross-country speeds in excess of 160kph (100mph)
Background:
Energy sources for Unmanned Vehicles

- Fossil fuel
  - Advantages: cheap, high specific power, COTS engines
  - Disadvantages: pollution, noise, must re-fuel, cannot start & stop easily

- Solar Electric
  - Advantages: Quiet, renewable, easy to start & stop, no pollution.
  - Disadvantages: Lower specific power, more expensive, climate and weather dependant

- Atmospheric Energy
  - Advantages: Free, strong, quiet, does not require special hardware (although advanced algorithms may require faster processor)
  - Disadvantages: Climate and weather dependant, usually limited to lower altitudes (h<10Kft), requires maneuvering which may upset sensor measurements

- Best use of atmospheric energy is to augment other sources of energy.
Background: Alan Cocconi

• Alan Cocconi flew the Solong UAV for 48hr using solar energy on June 1-3, 2005
  – Span = 15.6ft
  – Weight = 28.2lb
  – “The energy budget requires riding thermals.”
  – Cocconi also stated that the pilots/UAV operators were exhausted after 48hr of flying.
  – Moving map display with aircraft path was used by the pilots to soar in thermals.
John Wharington first proposed autonomous soaring for UAVs in 1998.

- Recursive learning was used to center updrafts. Neural networks were used to identify updraft positions.
- Algorithms were too computational intensive for real-time use.
- Framework for updraft modeling, simulation, and autonomous soaring was provided.
Test Hardware

- Cloud Swift Aircraft
  - Span: 4.26m (14ft)
  - Weight: 6.58kg (14.5lb)
  - Stall speed: 18kt
  - Mission speed: 25kt
- Piccolo Plus Autopilot
  - Weight: 212g (7.5 oz)
  - Sensors:
    - Rate gyros
    - Accelerations
    - Static & total pressure
    - GPS position & velocity
- Custom software developed for this project
Flight Test, Guidance and Control for Thermal Soaring
Flight Test Plan

Soaring research flights
- 4,000ft AGL altitude restriction
- Conducted on the edge of Rogers Dry Lakebed
- August – October, 2005
Flight Test Results

- 23 updrafts were autonomously detected and used
- Average height gain was 172m (567ft)

- Play cloudSwift_flt08_pr.mp2v
Thermal State Estimation
Thermal Drift Estimation

- Drift velocity was estimated from previous values of energy rate.
- Drift was used to define a new reference frame that is moving with the thermal.
Thermal Radius Estimation

• Thermal radius was estimated by iteratively fitting an assumed thermal velocity distribution to the energy rate measurements.

\[ W_{pred} = \left( w_{th} + V_e \right) e^{\left( \frac{S}{r_{th}} \right)^2} - V_e \]
Thermal Position Estimation

• Position was estimated by finding the position centroid of the measured energy rate.
• Advantages: Low computational cost, no tuning required, robust to variations in thermal size.
• Disadvantages: Bias toward the center of the measurement set.

\[ X_{th} = \frac{\sum X \cdot \dot{E}^2}{\sum \dot{E}^2} \]
Flight Test Results

- Soaring flight in light lift shown.
- Two small thermals encountered.
- Thermal centering performance could be improved.
  - Energy rate estimation delay.
  - Slow down when soaring.
- Altitude gain = 300ft
Mode Logic

• Simple mode logic was able to determine when to soar and when to search.
  – Input:
    • Total energy rate
    • Total energy acceleration
  – Output:
    • Soaring on/off
• Possible improvements:
  – Quicker estimate of aircraft energy
  – Additional mode that would allow the UAV to “Investigate” the thermal before moving on.
Flight Test Results

September 9, 2005

Highest climb in a single updraft shown.
844m (2770ft) altitude gain.

- Manual disengage to stay within airspace
- Start, waypoint navigation mode
- Updraft detection, switch to soaring mode

Play: cloudSwift_flt12_up2.igc
Flight Test Results
Flight Test Results

![Graph showing flight test results with various parameters such as aircraft altitude, velocity, throttle command, and acceleration over time.](image)
Flight Test Results

- Multiple thermals were used to soar autonomously for over an hour.
- Flight was limited only by actuator battery capacity.
- Altitude time-history is similar to that of migrating birds.
Concluding Remarks

- A guidance and control method was developed to detect and exploit thermals for energy gain.
- Latency in energy rate estimation degraded performance.
- The concept of a UAV harvesting energy from the atmosphere has been shown to be feasible with existing technology.
Questions?