Talk outline

• Introduction
  • *What is a MAV?*
  • *Why develop MAVs?*

• Technical challenges

• Airframe design and construction: *passive control*

• Vision-based flight stability: *active control*

• Current/future MAV work
What is a MAV?

*Flying vehicle with maximum dimension < 6 inches*
Why develop MAVs?

Desirable properties:

- Compact size (easy to carry a handful)
- Light weight
- Virtually silent and invisible from ground (stealthy)
- Cheap (~ $500/MAV)

Rapidly deployable/disposable remote sensor (visual/chemical/biological).

*Increased relevance since 9/11.*

Not like we are training rats to fly...
Some sample applications

- Video
- Remote views
- GPS/sensor data
- Supervisory commands
- Horizon tracking
- Target tracking
- MAV-based remote surveillance and sensor data collection
Some sample applications

Precise, Smart Micro Air Vehicle (MAV) Based Munitions

- MAV trajectory
- Target selection
- Video
- Target tracking/acquisition
- Vision-based flight stability

UF 6 MAV
UF 24 UAV
Remote view
Some sample applications

- MAV swarm with hydrocarbon sensors
- GPS satellite
- Supervisory swarm control
- Sensor/GPS data
- Swarm/data visualization
- Vision-based flight stability

Micro Air Vehicle (MAV) Based Explosives Detection
Research challenges

• Aerodynamics at low Reynolds numbers

• Stability and control
  • Sensors
  • Wind gusts
  • Small moments of inertia
  • No dynamic model

• Miniaturization of airframe, components and payload
  • Weight is key!

• Reliable propulsion and power
• Autonomy
• Collaborative control
Reynolds No. Dependent Degradation of Aerodynamic Efficiency

\[ \frac{C_L}{C_D} \text{Max} \]

Region of Interest

All Rigid, Smooth Airfoils

\[ \text{Re}_c = \frac{U}{c} \]
Biological Inspiration

- Biological systems outperform, in every aspect, small manmade aircraft
- Direct mimicry of flapping motion is very challenging
- Thin undercambered wings are more efficient than those with substantial thickness
- Birds and bats have flexible wings
- Nature does not have access to all mechanisms, such as propellers
- Propeller driven, fixed, flexible wings can provide a practical platform for MAVs
Adaptive Washout for Gust Suppression

Wing Deformation

Flow Direction

Wing During Gust

Wing Prior to Gust

Twist

Lift Response

Lift

Airspeed

Re Range

Rigid

Flexible

Adaptive Washout for Gust Suppression

Wing Deformation

Flow Direction

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Lift Response

Lift

Airspeed

Re Range

Rigid

Flexible
MAV with Video Camera

- Maximum Dimension
- Carbon Fiber Skeleton
- Latex Rubber Skin
- 52 grams, 1.8 oz.
- Hand Launched
- Speed 12-30 mph
Current State-of-the-Art MAV

- Color video camera/transmitter
- Maxon electric motor
- Lithium polymer batteries
- Miniature RC receiver
- 2 miniature rotary servos
- Fully proportional speed controller
International MAV Competition

Surveillance Competition
Fly to a target 600m away and transmit image back to the starting point

Payload Competition
Fly with 2 oz. metal block for two minutes and land on the field
MAV Competition History
NASA Langley
Wind Tunnel Tests

- **Multiple Wing Configurations**
  - Latex (1, 2 and 6 batten)
  - Graphite (rigid)
- **Two Fuselage Configurations**
  - Box (nominal)
  - Streamlined
- **Dyn. Pressure**: 1.0, 1.6 and 2.0 psf
- **Multiple Power Settings**
  - Power Off (prop pinned)
  - Trim Power
- **AoA**: -5 to 42.5 deg in 2.5 deg incr.
- **Sideslip**: -5 to 5 deg in 2.5 deg incr.
- **Symmetric Elevon**: -25 to 25 deg. in 5 deg. incr.
- **Antisymmetric Elevon**: -20 to 20 deg. in 5 deg. incr.
Flight Testing

Quantitative Assessment of Flight Quality
Stick Input Frequency Response

**Flexible wing**
- forward CG
- aft CG
- gusty wind

**Rigid wing**
- forward CG

**Frequency (Hz)**

Elevator input

Roll input
Vision-guided flight stability: active control

Why vision?

• Weight — using existing sensor
• Sensor availability/accuracy at MAV-scale (e.g. accelerometers)
• Biological inspiration: birds rely extensively on sharp eyes/vision
  • Proportionally large eyes
  • High visual acuity
  • Formation flying (ducks flying in V-shape)
  • Landmark-based navigation (migration)
Control system: block diagram

- Feedback control (RF)
- Video signal (2.4GHz link)
- MAV
- Video signal
- Video antenna
- Vision-based control
- Desired heading
Control system steps

1. Horizon detection
2. Bad attitude detection
3. Error detection
4. Kalman filter
5. PID control
6. Flight image
7. Servo controls
8. Recent history
Horizon detection: separating ground from sky

Underlying assumption:
- Ground looks like other ground
- Sky looks like other sky

Basic approach:
- Subsample hi-res image (e.g. to 80 x 60)
- Hypothesize coarse set of possible horizon lines (bank angle, pitch pct.)
- Compute statistics of hypothesized sky/ground regions in color space
- Minimize intra-class variance of sky and ground pixels; i.e. maximize:

\[ J_1 = \frac{1}{\Sigma_s + \Sigma_g} \]

\[ J_2 = \frac{1}{\Sigma_s + \Sigma_g + (\lambda_1^s + \lambda_2^s + \lambda_3^s)^2 + (\lambda_1^g + \lambda_2^g + \lambda_3^g)^2} \]

- Fine tune best coarse estimate (bisection search)
Horizon detection examples
Horizon detection examples
Post detection processing

- Bad attitude detection (e.g. no horizon)
  - Keep running statistics of recent ground/sky distributions
  - Compare current estimated statistics to time-averaged statistics

- Error (video noise) detection

- Kalman filtering

- PID control
Raw vs. filtered horizon estimate

Raw horizon estimate (bank angle, self-stabilized)

Filtered horizon estimate (bank angle, self-stabilized)
Raw vs. filtered horizon estimate

**Raw horizon estimate (pitch pct., self-stabilized)**

**Filtered horizon estimate (pitch pct., self-stabilized)**
Human-piloted vs. self-stabilized flight

**Bank angle (human piloted)**

**Bank angle (self-stabilized)**
Human-piloted vs. self-stabilized flight

Pitch percentage (human piloted)

Pitch percentage (self-stabilized)
Results summary

Horizon detection:
• Clean video — 99.9%+ correct identification

Flight testing:
• Extensive flight testing of vision control system over UF campus.
• Live demo of vision control system for US SOCOM (Fort Campbell, Kentucky).

Enabled capability: remote control from novice RC pilots
• Moi
• Audience member during demo for US SOCOM (Ft. Campbell, KY).
• Marty Waszak (NASA Langley sponsor)
Current and future work

• Smaller, lighter, better!
• Vision work:
  • Different features (e.g. texture for night flight)
  • Improved optimization criterion
  • Optical flow for improved state estimation
  • Target tracking and following
  • Landmark-based navigation
• GPS integration: the road to full autonomy
  • Developed light-weight on-board GPS receiver/transmitter
  • First successful tests this month (projected)
• Integration into UGV systems for remote sensing
• Remote chemical (hydrocarbon) sensing
• Collaborative control/multiple MAV flight deployment
• Immediate BDA (munitions-mounted)
• On-board computing
Interest is growing as practical systems are becoming realizable...

- **Past and current/approved funding:**
  - NSF: *general MAV research*
  - Special Ops.: *MAV prototype development*
  - NASA (Langley): *flight dynamics, dynamic modeling*
  - Air Force (Tindall): *UGV-launched MAVs for remote sensing*
  - Air Force (Eglin): *immediate BDA, smart munitions*

- **Pending:**
  - U.S. Army (Huntsville): *remote hydrocarbon sensing*
  - DOD: *anti-terrorism technologies*
To learn more:

http://aeroweb.aero.ufl.edu/~microav

http://mil.ufl.edu/~nechyba/mav