Aerial Robots: Airframes, Sensing and Navigation

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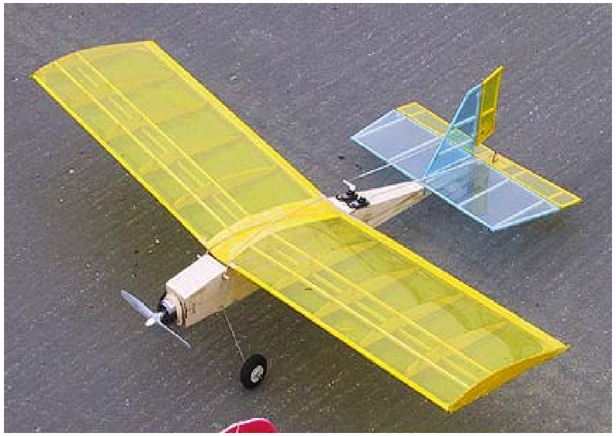
Talk Description: This talk concerns flying robots with lighter-than-air, fixed- and rotary-wing designs.

Subtopics:

- *Robotic helicopters, Blimps, Micro-Air-Vehicles*
- *Sensing for autonomous flight*

Rotary-wing: USC, Berkeley, MIT, CMU, Georgia-Tech, CSIRO, Yamaha, JPL



Fixed-wing: Florida, Arizona, BYU, Sydney. Hong Kong, AeroVironment

Blimps: U Penn, LAAS, JPL, INRIA

Novel: Micromechanical Flying Insect (Berkeley), Mesicopter (Stanford), Entomopter (Georgia Tech), Indoor Flying Robot (EPFL), Closed-Quarter Aerial Robot (Drexel)

Major Labs and Status

1. USC – Gaurav Sukhatme

   Recently celebrated 10^{th} anniversary with 3^{rd} generation robotic helicopter (hobby-size gas engine). First to achieve milestone: autonomous landing using computer vision. Currently integrating wireless sensor networks (Motes) into research

2. UC Berkeley – Shankar Sastry

   Robotic helicopter (Yamaha R-Max): hybrid and multi-vehicle (airborne and ground teams) control. Current work focus has been on pursuit-evasion games and learning.

3. University of Florida (Gainesville) – Nechyba et al

   Fixed-wing hand-sized miniature air vehicles (40 MPH cruising speed). Computer-vision based autonomously flight control (GPS way points, horizon detection – no collision avoidance capabilities)

Major Labs and Status continued

4. UC Berkeley – Ron Fearing

Micro-mechanical Flying Insect (MFI) project. Fly-sized airframe driven by piezo actuated flapping- wings. Goal of un-tethered hovering expected within next few years.

5. University of Pennsylvania – GRASP Lab

V. Kumar et al: visually servoed a 9-meter robotic blimp.
G. Pappas: cooperative distributed multi-vehicle formations with fixed-wing aircraft is recent work.

6. Georgia Tech Research Institute – Robert Michelson

50-gram flapping wing vehicle (entomopter). Reciprocating chemical muscle actuators. Progress since 2002 is unclear but focus appears to be on concept vehicles for Mars exploration

Major Accomplishments in Past Decade

C. 1991 – Michelson (AUVSI President) hosts first competition and began robotic helicopter development at schools like CMU, Georgia Tech and MIT. Competition has been held annually since 1991.

C. 1993 – Dickenson publishes work on winged insect flight dynamics which spawns development of flapping-wing aerial robots like Fearing (Micromechanical Flying Insect), Michelson (entomopter) and Kroo (mesicopter) and flying insect vision (Srinivasan).

C. 1995 – DARPA announces MAV program (miniature, hand-sized fixed-wing vehicles). AeroVironment, Univ. Florida, Arizona and BYU consequently began demonstrating oval planform configurations and GPS way-point navigation

C. 1999 – Sukhatme was first to successfully land a robotic helicopter using computer vision demonstrating GPS, vision and wireless technologies sufficiently mature for aerial robot development

C. 1999 – Sastry demonstrates multi-vehicle coordination using both airborne and ground robots. This endeavor spawned work on pursuit-evasion games, hybrid, distributed and software enabled control..

C. 2003 – Oh (Drexel) first to demonstrate autonomous collision avoidance, altitude control and landing on an un-tethered, fixed-wing 30-gram aerial robot using optic flow. Work spawns interest in non-GPS based navigation in near-Earth environments

Most Influential Papers in the Past 10 Years

Saripalli, S., Montgomery, J., Sukhatme, G. "Vision-based Autonomous Landing of an Unmanned Aerial Vehicle", IEEE ICRA, pp. 2799-2804 V3, Washington D.C., May 2002.

M. Ettinger, M. C. Nechyba, P. G. Ifju and M. Waszak, "Vision-Guided Flight Stability and Control for Micro-Air-Vehicles", IEEE IROS V3, pp. 2134-40, 2002

Fearing, R.S., et al "Wing Transmission for a Micromechanical Flying Insect", IEEE ICRA San Francisco, pp. 1509-1516, April 2000.

Amidi, O., Kanade, T., Fujita, K., "A Visual Odometer for Autonomous Helicopter Flight", *Robotics and Autonomous Systems*, V28, pp. 185-193, 1999.

Zhang, H., Ostrowski, J.P., "Visual Servoing with Dynamics: Control of an Unmanned Blimp", *IEEE ICRA*, pp. 618-623, Detroit MI, 1999.

Mueller, T.J., "Aerodynamic Measurements at Low Reynolds Numbers for Fixed Wing Micro Air Vehicles", *RTO AVT/VKI Special Course on Development and Operation of UAVs Military and Civil Applications,* Belgium, Sept. 1999.

Shim, H., Koo, T.J., Hoffmann, F., Sastry, S., "A Comprehensive Study of Control Design for an Autonomous Helicopter", *IEEE Conference on Decision and Control*, Tampa FL, pp. 3653-3658, Dec. 1998

Srinivasan, M.V., Chahl, J.S., Zhang, S.W., "Robot Navigation by Visual Dead-Reckoning: Inspiration from Insects", *Journal Artificial Intelligence and Pattern Recognition*, V11, pp. 35-47, 1997.

Major Unsolved Problems and Challenges To Overcome

Vehicle performance difficult to acquire, assess and validate because flight conditions are often dynamic and unpredictable (e.g. wind and lighting). Absence of data has led to ad hoc design. Consequently experiments performed by other institutions fail to yield similar results.

Creating sensors and algorithms for autonomous collision avoidance and localization without GPS is a challenge. If overcome, flying in near-Earth environments (forests, tunnels, and inside buildings) could be realized..

Making propulsion systems that are light-weight, low-noise and provide longer flight times is an engineering challenge.

Communications that is robust, secure and unjammable is an unsolved problem. Improved this technology would vertically impact the development of distributed and multi-vehicle systems (e.g. swarms).

Program Recommendations

Increased funding in the following would vertically advance aerial robotics

1. Sensors for autonomous collision avoidance and localization

   Non-GPS examples include optic-flow, echo-localization and ultra-wideband radar. Algorithms to compensate for GPS drop or inertial measurement unit drift also needed.

2. Test rigs and Reliable Aerial Platforms

   A safe, low-cost (less than $50K), easy-to-fly platform that enables investigators to easily retrofit sensors is needed to acquire flight data and validate controller designs. Alternatively, test rigs can be designed to provide such data.

3. Novel Propulsion Systems`

   Turbines, ducted fans, heavy-fuel engines, fuel-cells are example systems that can be developed to deliver increased lift in a smaller footprint and noise signature

4. Communication Systems

   Light-weight, low-power robust, reliable and unjammable devices needed in order to physically realize flying swarms and distributed systems.

Major Accomplishments Outside the US

1. EPFL Lausanne Switzerland – Roland Siegwart and Dario Floreano

   Indoor-flying prototypes: fixed-wing, blimps and rotorcraft. Prototypes manually controlled or tethered. Summer 2004 demonstrated autonomous optic-flow based collision avoidance.

2. University of Sydney Australia – Hugh Durrant-Whyte

   ANSER: Autonomous Navigation and Sensing Experimental Research program demonstrates decentralized data fusion and SLAM methods on multiple UAVs.

3. Australian National University – Srinivasan and Chahl

   Flying insect inspired algorithms, sensors and vision-guided robots. Demonstrated corridor following, hover-control and terrain following using optic flow on rotorcraft.

Major Accomplishments Outside the US continued

4. LAAS/CNRS France – Simon Lacroix and Philippe Soueres

   Robotic blimp: Key focus and accomplishments have been in vision-based autonomous flight control and environmental mapping. Joint projects (e.g. AURORA) with European universities in Spain and Portugal

5. Technical University of Berlin Germany – Gunter Hommel et al

   Robotic helicopter (MARVIN) won multiple years in the annual AUVSI robotic helicopter competition. Little has been published. Demonstrated tasks like target identification, GPS waypoint navigation and flight stabilization.

6. City University of Hong Kong – Dong Sun et al

   Fixed-wing miniature aerial vehicle. Demonstrated GPS waypoint navigation and flight control. Custom designed inclinometers, wireless communication equipment and flight control units.

International Cooperation Recommendations

1. Asia: Low-cost, Easy-to-Fly Vehicle Development

   Ironically, Japan and Taiwan have many hobby-scale helicopter and airplane manufacturers but few university-level UAV research groups. US partnerships leading to an easy-to-fly and affordable flying platform would advance that state-of-the-art.

2. Switzerland: Indoor Flying Robots

   EPFL Lausanne and ETH Zurich have been developing 50-gram fixed- and rotary-wing vehicles and optic flow sensors. Such effort has led to micro-motors and blue-tooth communication devices.

3. Australia: Flying Insect Inspired Systems, SLAM and Visual-Servoing

   Srinivasan, Durant-Whyte and Corke (all in Australia) have developed low-cost sensing and localization devices. Aerial test beds include hobby-scale rotorcraft and fixed-wing aircraft.