Current State of the Art of Micro Air Vehicles

By Alan Kendrick J.D., Nerac Analyst

Introduction

Micro Air Vehicles (MAV) and Micro Flyers are a class of unmanned air vehicles that are extremely small and by necessity, extremely maneuverable. These devices are on the order of 20 cm in size weighing less than 100 grams; about the size of a small bird or larger flying insects. The demonstrated and proposed uses for these MAV are numerous and span both military and civilian applications.

MAV development was born in the early '90s from microsystems (Micro-Electro-Mechanical Systems, or MEMS) research by the Rand Corporation, and subsequent research by MIT regarding micro flyers. The MEMs research provided the miniaturization of sensors, controls, communication devices, mechanical systems and packaging required for MAV, and the Lincoln Laboratory at MIT provide feasibility studies for micro flyer designs. The results of these two research programs laid the foundation for DARPA's Micro Air Vehicle (MAV) program.

Applications

Military Applications

The use of MAV in military applications is quite wide and provided the impetus for early MAV development. The development of military MAV is primarily focused on uses for platoon and troop level deployment. MAV use in reconnaissance and surveillance operations, battlefield situational awareness and dynamic analysis resources, and rescue operations are uniquely situated for field operations. Remote positioning of sensors, like birds perching in a tree, can provide remote biohazard and hazardous materials detection, real time day and night imagery surveillance, infra red and audio monitoring. Mobile MAV deployments include mine field scanning, hazard conditions monitoring (real time tracking of hazardous clouds, their size and location), troop deployments and strength assessments, pinpoint target designators (is that a real fly on your back?), and offensive payload capabilities. Other field uses include rescue operations; location devices and beacons for downed pilots and situational awareness means for the downed pilot.

Civil

Civil use of MAV, at least initially, was a cross-over from military applications. Primary deployments included police reconnaissance and surveillance, crowd control, border surveillance and control, and search & rescue operations. More recently, MAV have been used for search and rescue operations, the remote monitoring and detection of chemical leaks and biohazards, pollution monitoring, and traffic management and accident documentation. Advance uses of MAV in rescue operations provide guidance and warning devices for police and firemen to help locate victims and suspects, or provide real time warnings concerning emanate threats.

MAV are also deployed for real time inspection of remote utilities and pipelines, remote forest inspection and wildlife surveys (including measurement, data collecting and tracking), and agricultural monitoring. MAV may be used for fertilization, pest control and pollination in agricultural operations.

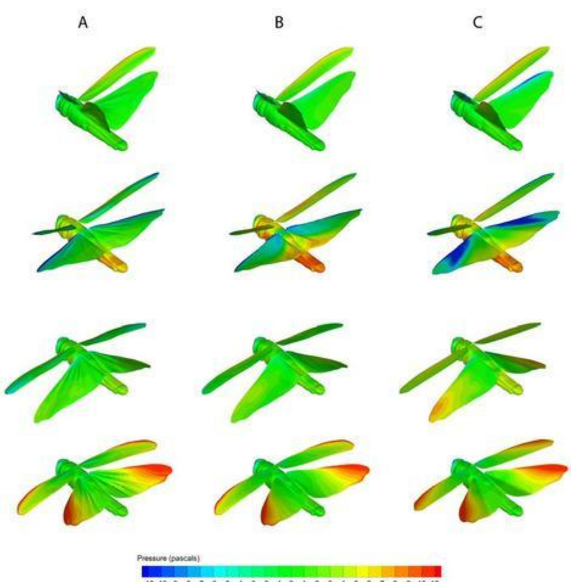
Other civil deployment possibilities include commercial applications for property surveys and inspections, mobile advertising, news investigations and reports, and displayed or projected media for entertainment shows (e.g. thousands of synchronized MAV lighted and mobilized).

MAV Engineering Challenges and Bioinspired Designs

MAV designs are heavily influence by biomimetics and biomimicry; the study of nature’s designs and processes for the purpose of imitating or taking inspiration from these designs and processes to solve complex problems. Indeed, the idea of bio-inspired designs not only drove the MAV engineering design perspective, but also the scientific communities’ ongoing interest in creating a mechanical flapping winged device that would mimic the flight of a bird or flying insect.

Aerodynamics and Flight Control

One of the main issues with the development of MAV was in understanding the aerodynamics of a flapping winged aircraft. Scientists and engineers are just beginning to fully understanding the flight mechanisms and aerodynamics of a bird in flight or a flying insect. Recent imaging techniques have provided the ability to study the aerodynamic shape and flight performance of a MAV using 3D stereoscopic vision to obtain the 3D information of the aircraft's flexible aerodynamic surfaces. These studies allow designers to make improvements in wing structure and motion design to better approximate a natural wing. Recent interesting innovations include variable compliance wings with membranes that react to electromagnetic stimulations. Membrane wings with variable compliance greatly improve the maneuverability and performance of MAV by allowing the wing to change shape and tighten or loosen the skin. This is particularly useful in the low Reynolds number flight regimes in which these vehicles operate where the aerodynamic efficiency of airfoils and wings decreases dramatically. Recent research focused on the mechanical properties and aerodynamic performance of a low-aspect-ratio membrane wing with variable compliance has shown that maneuverability is improved and lift is significantly increased when the wing is forced with an oscillating field at specific frequencies. It is suspected that changes in membrane wing compliance might be used by flying animals, such as bats, to control aerodynamic performance.



Scientists studying the flexible wings of insects have discovered what makes them so efficient compared to the rigid wings of manmade aircraft. Researchers at Oxford University and the University of New South Wales first used high-speed video cameras to capture how locust wings change shape in flight, then computer modeling to reconstruct these shape changes in 3D, and finally ran simulations to discover how they deliver the sort of efficient flight that enables tiny locusts to make inter-continental flights. [1]

[1] *Tiny flying machines inspired by nature will revolutionize surveillance work*. EPSRC Press release, July 28, 2011.

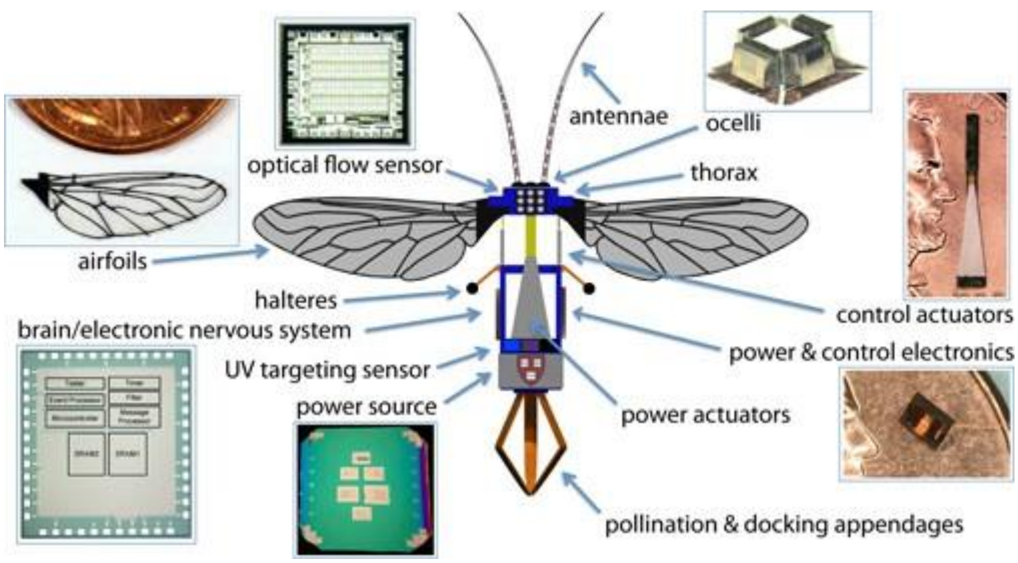
Autonomous Flight

Some of the greatest challenges in the development of MAVs involve flight stability and control. MAV low moments of inertia make them particularly vulnerable to wind gusts and rapid accelerations. Flight in the low Reynolds number regime negatively affects both wing lift-to-drag ratios and propeller efficiencies. A highly integrated flight control system providing autonomous stabilization is required to counter these low speed effects. Most MAVs can self-stabilize and hold a commanded position by using control loops that process GPS and vehicle inertial measurements. However, current R&D is focused on creating MAVs capable of autonomous flight not only for dynamics and flight control, but also for navigation and collision avoidance, and ground object recognition and tracking. These are best accomplished through the use of a unified vision system which employs real time image feature extraction, horizon detection and ground-sky segmentation, and contextual ground object detection.

Traditional navigation and flight control systems using accelerometers and gyroscopes provide information only on the state of the system at a point in time; aircraft's position is determined from a previous know position through monitoring of gyroscopic attitude and force accelerations. Vision based autonomous flight systems provide information regarding the environment and the information provided may also be used to determine the MAV's current state in that environment. Vision based systems are more versatile as the system can process information regarding flight path and obstacles, and then integrate with information regarding the state of the system in order to determine the most appropriate control and maneuvering for the task at hand, e.g. flight path planning, collision avoidance or object tracking. Hence, vision based systems allow the MAV to react to its environment in an anticipatory manner.

Bioinspired Imaging Sensor Designs

Small, fast and highly responsive sensors are required to provide the feedback and control necessary for autonomous flight of an MAV. It is believed that insect visual stabilization and guidance is performed by analyzing the visual information received from its own flight motion. Retinal slip speed or optic flow is the speed at which insects see contrasting features slide across their retina. Motion detecting neurons in the insect's visual system assist in processing the optic flow information. Similar to insect navigation and control, a bioinspired design of navigation and control for MAVs will include optic flow sensors for collision avoidance, altitude control and landing, antenna to measure wind velocity, and ocelli or light sensors to determine orientation.



A MAV bee using a biomimetic ocelli senses light levels with four phototransistors to estimate the angle orientation relative to vertical; optic flow micro sensors to measure the MAV perceived motion and provide information for collision avoidance, altitude and landing; and biomimetic antennae for rapid feedback of wind velocity. Robobees: Harvard School of |Engineering and Applied Sciences.

Stability and control is fundamental to achieving autonomous MAV flight capabilities and has presented some of the most difficult engineering challenges in MAV development. The use of traditional aircraft rate and acceleration sensor technologies in MAVs has proved difficult to incorporate at the MAV scale and weight, and Micro Electrro-Mechanical Systems (MEMs) containing rate gyros and accelerometers, although meeting the size and weight requirements, have high drift rates and are highly sensitive to temperature fluctuations. For many MAV applications, flight stability and control using a vision based system incorporating bioinspired design sensors may be the only practical solution to achieving autonomous flight.

About the Analyst

Alan Kendrick J.D.

Alan Kendrick specializes in mechanical and aerospace systems and provides clients with technical and intellectual property support.

He worked for the systems engineering division of NASA's Ames Research Center in Northern California for twelve years as a mechanical/aerospace design engineer. While at NASA, Alan worked on a variety of design projects including wind tunnel design, modification and modernization, design and structural analysis of aircraft modification projects, biomedical and human habitat research equipment, electro-mechanical hardware modernization, design, selection and integration with mechanical systems, space flight hardware, and large facility piping and piping structure analysis and design.

Credentials
J.D. University of San Francisco
B.S. Magna Cum Laude, Aerospace Engineering, San Jose State University
Bar Member, U.S. District Court – Northern District of California
Bar Member, U.S. District Court – Southern District of California
Bar Member, Supreme Court of California

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