

Micro Air Vehicle – A Pocket Sized Flying Aircraft, Military Asset and a Boon to Mankind- An Overview

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Abstract: The advancement in computational power and electronic miniaturization as well as maturation of micro electromechanical (MEMS) sensors and actuators have lead to the emergence and development of a new class of small flying aircraft called as Micro air vehicle (MAV) that have drawn tremendous attention worldwide in recent years. In this paper a general overview is presented on the practical applications of MAVs for military missions such as battlefield reconnaissance, damage assessment, visual surveillance, biological or chemical agent sensing and for civil missions such as search and rescue, border patrol, air sampling and commercial operations etc. The paper also focuses on the aerodynamics of the flight control for propulsion and hovering.

Keywords: Micro air vehicle; Micro electromechanical (MEMS) sensors; Surveillance; Aerodynamics of flight control; Propulsion; Hovering.

I. Introduction

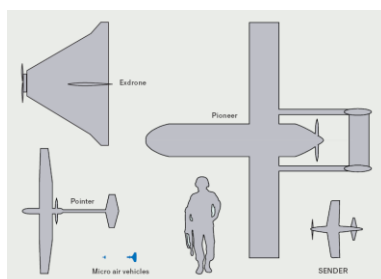
The Micro air vehicles is a small unmanned aerial vehicle (UAV) built by Honeywell. The MAVs unique design represents a new generation of light weight, low cost UAVs. The MAV and the accompanying ground station can be transported in a backpack by a single soldier, providing unprecedented situational awareness to front line commanders, and short-circuiting the traditional long Intelligence chain to the field. The airframe is a ducted fan design allowing the MAV to hover and stare for extended periods of time. Made of light weight composite materials, the air frame encloses a bladder style fuel tank which provides consistent fuel flow to a small engine, regardless of vehicle orientation. The MAV is fitted with forward- and down-looking cameras, which are located in a payload pod. Exchangeable pods, containing different types of sensors, can be easily mounted in the field without tools [1].

MAVs should be thought of as aerial robots, as six-degree-of-freedom machines whose mobility can deploy a useful micro payload to a remote or otherwise hazardous location where it may perform any of a variety of missions, including reconnaissance and surveillance, targeting, tagging and bio-chemical sensing.

A. Problem statement

The current surveillance assets, such as satellites manned aircraft, and unmanned air vehicles, possess virtually no capability to gather information inside buildings and other confined spaces. The term, Micro Air Vehicle, may be somewhat misleading if interpreted too literally. We tend to think of flying model aircraft as "miniature", so the term "micro" now alludes to a class of significantly smaller vehicles. But MAVs are not small versions of larger aircraft. They are affordable, fully functional, militarily capable, small flight vehicles in a class of their own. The size of the MAVs as compared to existing air vehicles is shown in Fig. 1.

Figure 1 Size comparison of existing air vehicles and MAVs



This hand-held, autonomous flying vehicle is motivated by a need for intelligent reconnaissance robots capable of discretely penetrating confined spaces and maneuvering in them without the assistance of a human pilot.

B. Proposed technology

The Bio-inspired engineering of exploring system focuses on using the variety of nature tested mechanisms successfully implemented by biological organisms but not easily accomplished by conventional methods [2], [3]. Here we apply BEES technology to the development of bio-inspired visual navigation sensor integrated on small flyers to enable autonomous flight. This is illustrated in Fig. 2.

The inspiration for these designs was from insects. Although most insects have immobile, fixed focus eyes stereoscopy [2], [6], [7]. Distilling these principles from biology enables the development, efficient, compact, yet sophisticated autopilot for robotic aircraft embarking on planetary exploration missions. These tiny robotic flyers, called Micro air vehicles (MAVs), will be able to buzz over enemy territory nearly unnoticed by the enemy troops below. Few would even look twice at these dime-sized flying robots.

Figure 2 Biologically inspired control approach



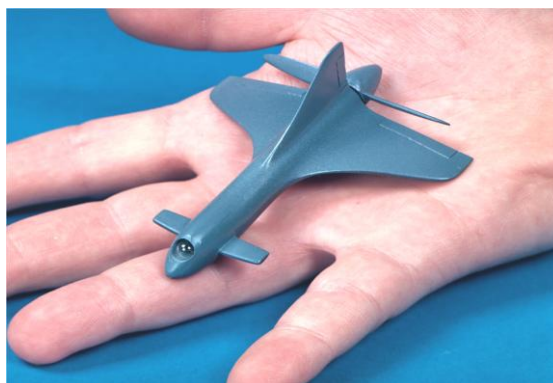
This paper is organized into sections as follows. In section II the architecture of the MAV is discussed. The section III deals with the aerodynamics and vehicle configuration of MAVs. The MAV applications are detailed in section IV. In section V the scope for future work is discussed. The concluding remarks are presented in section VI.

II. Architecture of MAV

A. Making of MAV

To the human eye, an MAV in flight would resemble a small bird. MAV radar signatures would be similar to those of small birds and are thus likely to be lost in clutter. Furthermore, the projected MAV airspeed of 10 to 15 m/sec is below the minimum detectable velocity for most radar. Infrared search-and-track units would be able to detect an MAV only at short ranges because of its low power. For an electrically powered MAV, the acoustic signature would be dominated by the aerodynamic noise of the propeller, and would be audible only at close range. An MAV powered by an internal-combustion engine with a muffler could achieve similar acoustic performance. The Fig. 3 illustrates the smallest possible MAV with a wing span of 7.4cm.

Figure 3 MAV with a wing span of 7.4cm

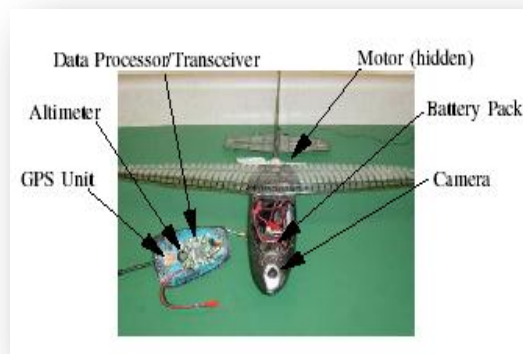


B. External Architecture of MAV

In order to build the MAV, many experiments are performed to learn how flies fly. One of the experiments involved building a pair of robotic wings, called Robofly, which was made of Plexiglas and modeled after the wings of a fruit fly. The wings were immersed in a tank of mineral oil, which forces them to react like smaller, 1-millimeter-long fruit-fly wings beating rapidly in the air. Six motors three on each wing moved the wings back and forth, up and down and in a rotary motion. Sensors were attached to measure the force of the wings [8]. Eventually, the Robofly will be shrunk down to a stainless-steel micro robotic fly that is 10 to 25 millimeters (0.4 to 1 inch) in width and weighs roughly 43 milligrams (0.002 ounces). The wings will be made of a thin Mylar film. Solar power will run a piezoelectric actuator that will push the wings to flap. The robot's thorax will transform piezoelectric-actuator deflections into the large wing stroke and rotation required to achieve flight.

For the robot to fly approximately 90% of the force required for lift has been achieved experimentally with a fully operational, two-wing structure. The next step will be to add a flight-control unit and communication unit for remote control. Thus they are working on enabling controlled hovering by way of optical sensing and an onboard gyroscope. The Fig. 4 shows the MAV Components.

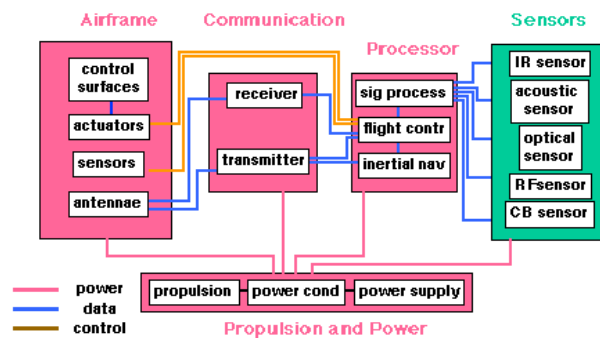
Figure 4 MAV components



C. Internal Architecture

The physical integration challenge is believed to be the most difficult problem, the degree of which increases dramatically with decreasing vehicle size or increasing functional complexity. At and below the 15 cm scale size, the concept of "stuffing" an airframe with subsystems - our conventional approach to hardware integration - becomes extremely difficult. An examination of the range of system elements illustrates the problem as shown in Fig. 5.

Figure 5 MAV System integration



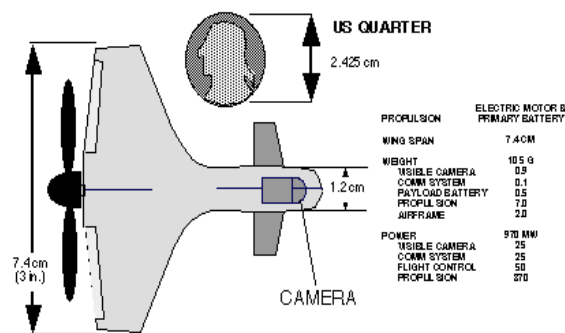
Many of the system functions depicted will be provided by microelectronics or MEMS-based components. Even so, separate modules for each function would consume more volume than may be available. From an electronics perspective, the on-board processor and communications electronics form the core of the vehicle [1], [8]. They provide critical links between the sensor systems and the ground station, and they are vital to the flight and propulsion control systems. In the scheme depicted in Fig. 5, Power generation and propulsion subsystems

support critical electronics and flight control functions in addition to flight propulsion power. The multifunctional required by the MAV weight and power budgets may be achieved only by a highly integrated design, with physical components serving multiple purposes, or accomplishing multiple and often diverse functions. For example, the wings may also serve as antennae or as sensor apertures. The power source may be integrated with the fuselage structure, and so on. The degree of design 'synergy' required has never been achieved in a flight vehicle design [13].

D. Panoramic Imaging system of MAVs

Panoramic Imaging means 360degree imaging. Fig. 6 depicts a tiny video panoramic camera system employed in the MAV. The camera would weigh only 1 gram and occupy roughly one cubic centimeter, as shown in comparison to a deer fly. The camera would have 1600x1600 pixels and require as little as 25 mill watts of power. In some MAVs they Use Optical mouse chip which captures the images at a speed of 2300 frames per second. While the cameras look like webcams, they offer machine vision grade camera images. They offer also a global shutter (CCD), which prevents the edge artifacts a rolling shutter.

Figure 6 MAV Camera concepts.



E. Limitations

Systems integration for the MAV to meet low mass and volume requirements and to permit low-cost mass production requires close interaction among multiple disciplines. The close proximity of vehicle subsystems also provides challenges such as control of heat dissipation, vibration from internal-combustion engines, and electromagnetic interference from electric motors. Because conventional aircraft integration technology does not apply at the MAV scale, new approaches must be developed.

III. Aerodynamics and vehicle configuration

In order to layout all physical components properly in the MAV, some important wing reference indices such as wing plan form, the MAC (Mean aerodynamic chord), the CG (Centre of gravity) can ensure the balance of the vehicle and hence guarantee more stable and safe flight. Furthermore the aerodynamic performance of the airfoil sections at low Reynolds number must be investigated so that efficient wing shapes can be obtained.

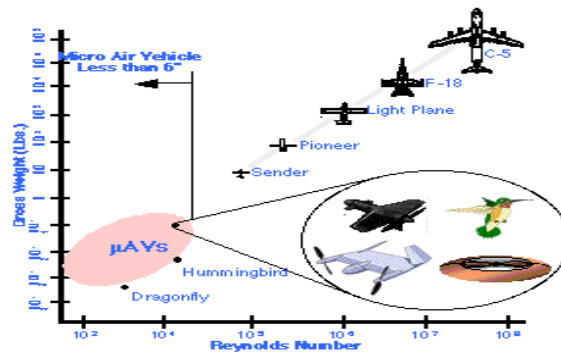
A. Aerodynamic design

The aerodynamic design of MAVs offers unique challenges because of the relatively low Reynolds-number flight regime in which they fly. The Reynolds number is a non dimensional similarity parameter that relates inertial forces to viscous forces, and is proportional to the flight speed times a characteristic length, such as the wing chord. MAVs would operate at low Reynolds numbers of 20,000 to 50,000. The viscous forces are more significant than those experienced by conventional aircraft in flight, and the MAV would experience increased drag, reduced lift to drag ratios and reduced propeller efficiency [12]. Wind boundary layer airflow would be laminar rather than turbulent as found in conventional aircraft, and boundary layer separation effects must be taken into account. The Fig.7 shows the MAV flight regime as compared to the existing flight vehicles as is evident from the Reynolds number.

B. Propulsion

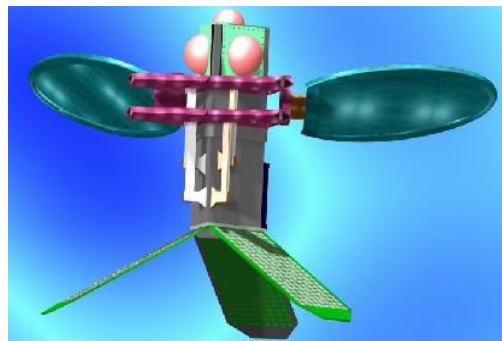
Having explored the lift to drag ratio for the MAV, we now need to consider the power required for the Vehicle. The flight power (air speed times thrust) shaft power and electric power needed for a range of MAV sizes with the requirements of the 15cm wingspan. For conservative choices of lift-to-drag ratio and CL , the baseline flight power is 1.25 W.

Figure 7 The Micro Air Vehicle Flight Regime Compared to Existing Flight Vehicles.



For a propeller efficiency of 50%, the baseline shaft power is 2.5 W. If we use an electric motor with 60% efficiency, the baseline electrical power is 4.2 W. These values, however, provide only enough power for level flight, and they must be doubled so that the MAV can turn, climb, and fly in gusty air. To produce this power, we considered a variety of efficient and lightweight propulsion systems, including electric motors powered by batteries or fuel cells, internal-combustion engines, turbines, compressed gas, and power plants using flywheels or capacitors for energy storage. The Fig. 8 shows the MAV with two wings and a propeller.

Figure 8 MAV with two wings and propeller



C. Flight control

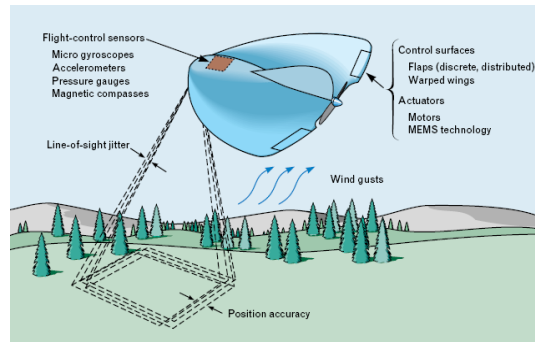
Aerodynamic and propulsion factors limit the MAV to narrow ranges of airspeed and angle of attack, rendering the vehicle more vulnerable to gust upset. Flight control allows the MAV to fly at low airspeed in the presence of wind gusts and turbulence, stabilizes the vehicle with the aid of appropriate sensors, and provides aerodynamic controls, because the MAV airframe dynamic modes, such as Dutch roll and the short-period longitudinal mode will occur at higher frequencies compared with larger vehicles, the MAV will need some means of augmenting the natural stability of the airframe. In addition, the MAV should have the capability to fly itself to preprogrammed waypoints selected by the operator.

Micro size pressure gauges and accelerometers are currently available and miniature magnetic compasses may also be feasible soon. Most useful for this application, however, are rate sensors. Microchip angular-rate sensors are now being produced and will be useful for MAVs as soon as they are mated to miniaturized readout electronics. Drift rates from these sensors will be adequate for vehicle stabilization applications. The ability to generate aerodynamic forces and moments is also required to stabilize and maneuver the MAV. The MAV flight control system is shown in Fig. 9.

D. Optical sensors

Without optical sensors, an MAV would be just a pocket-sized, high-tech model airplane, unsuitable for surveillance operations [8]. Like all MAV components, these sensors must meet small mass and power requirements: sensor mass must be under 2 g and power consumption under 100 mW. These parameters are one to several orders of magnitude smaller than for any commercial cameras available today. In addition, surveillance missions require high-resolution sensors with the ability to see in the complete range of outdoor light levels, from noonday sunlight to overcast starlight. These optical sensors must have high resolution (approximately 1000 x1000 pixels) for recognition of human figures at the mission altitude of 100 m. Flight control requires sensors that measure motion (roll, pitch, and yaw) of the MAV, and aerodynamic control inputs that stabilize and maneuver the MAV in wind gusts and turbulence.

Figure 9 MAV flight control system



IV. Applications of MAV

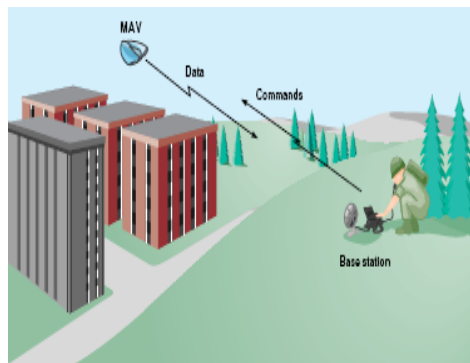
A. Military operations

One of the primary military applications envisioned for MAVs is the gathering of intelligence (through the surreptitious use of cameras, microphones, or other types of sensors); among the more extreme applications posited for such devices is that they may eventually be used as "swarm weapons" which could be launched en masse against enemy forces.

The Significant potential exists for MAVs to be used by the front line war fighters as a disposable agent for look-ahead reconnaissance and surveillance for tactical and anti-terrorist operations. The MAVs also aids the military sector in bomb damage assessment, or evacuating the injured within an unfamiliar territory is dangerous and also requires a large, diverse task force. However the MAVs could assist in such missions by providing situational awareness without risking the life of soldiers, first responders or other personnel [9].

A Micro air vehicle flies over a simulated combat area during an operational test flight. The MAV is in the operational test phase with military explosive ordnance disposal (EOD) teams to evaluate its short range reconnaissance capabilities. The Fig. 10 illustrates the military application of MAVs.

Figure 10 MAV employed for reconnaissance and anti-terrorist operations



The Fig. 11 shows the MAV deployed in Iraq specially to identify improvised explosive devices from the sky. Here the MAV operates like a small remote controlled helicopter and can easily fly down to inspect hazardous areas for threat without exposing the soldiers to enemy fire.

Figure 11 MAV deployed in Iraq for military use



MAVs will become a vital element in the ever-changing war-fighting environment and will help ensure success on the battlefield of the future. The MAVS will work in concert to patch together a wide, detailed view of the battlefield - singling out individual targets without losing sight of the broader scene. Data will be communicated among the MAVs to enable real time, reliable decision-making and to provide an advanced overall picture for other platforms or operators. This is illustrated in Fig. 12

Figure 12 MAV looking like a pigeon like drone that can draw power from an electrical wire while its camera watches a target



B. Biochemical sensing

Biochemical sensing, as illustrated in Fig. 13 is another potential mission for MAVs. With gradient sensors and flight control feedback, MAVs will be able to map the size and shape of hazardous clouds and provide real time tracking of their location.

Figure 13 MAV as a Mobile immersion sensor



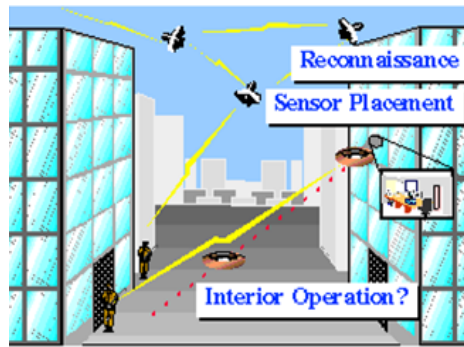
C. Urban operation missions

In urban operations as shown in Fig. 14, MAVs acting in small, cooperative groups, will enable reconnaissance and surveillance of inner city areas, and may serve as communication relays. They may also enable observations through windows, and sensor placement on vertical and elevated surfaces. Their application to building interiors is the most demanding envisioned. The capability to navigate complex shaped passageways, avoid obstacles and relay information will require yet another level of technology. Other uses include traffic monitoring, Wildlife surveys, power line inspection and real estate aerial photography.

D. Natural disaster and navigation

Recently there is a need to acquire intelligence in hostile or dangerous environments. More often homeland security, search and rescue and disaster mitigation efforts have taken place in unforeseen environments which include caves, tunnels, forests, cities and even inside urban structures [7]. MAVs would be invaluable in the aftermath of natural disasters such as for the inspection and search for survivors in the interior of hazardous environments such as damaged nuclear power plants, burning structures, earthquake stricken areas, tornadoes and landslides [9].

Figure 14 MAV used in urban applications



E. Exploring systems

Robotic flies could also be well-suited as a new generation of interplanetary explorers. Their ability to crawl and fly also gives them an advantage in exploring other planets. Most likely, NASA would send dozens of these surveillance vehicles to explore other planets.

F. Autonomous hovering of MAVs

The MAV's propulsion is based on two fixed pitch counter-rotating rotors, driven by a single electric motor. Counter-rotation minimizes net torque and gyroscopic effects on the MAV body. The rotors are protected by a fixed tip shroud. The shroud improves lift efficiency and also serves as a structural member for protecting the MAV rotors and housing micro-electronic sensors and antennae. The MAV stabilization in roll and pitch and side to side translation are achieved via control vanes attached to the body within the rotor wash, and actuated by micro-brushless motors. Attitude damping is achieved by another set of fixed Vanes attached to the body. Roll and pitch measurements are made by MEMs based accelerometers placed at the MAV center-of-gravity and rate gyros [2], [8].

Back packable, bird-sized aircraft or Micro Air Vehicles (MAVs) can be rapidly deployed to provide an “over-the-hill” or “around-the-corner” perspective from a remote location. Moreover, a fixed-wing platform capable of hovering would allow potentially long hover and stare modes while maintaining long flight times and a dash capability to avoid enemy fire. The hovering mode would also allow flight in caves, tunnels, and other tight, enclosed labyrinths as shown in Fig.15.

Figure 15 A fixed-wing MAV transitions to hovering mode to gently maneuver itself through a small opening of an urban structure.



V. Scope for future work

Beyond miniaturized and power efficient electronics, serious developmental issues remain in the areas of power and propulsion for MAVs. Moreover, while maximization of performance parameters are desirable attributes for most applications, range, endurance, speed, maneuverability and hover are the elements needed to improvise and best optimize by the mission requirements.

The future work will also focus on the following aspects: to perform analysis of the aerodynamics by using low Reynolds number, to further optimize the design based on different criteria such as weight reduction, wing size and power consumption.

VI. Conclusion

Research and developments related to Micro Air Vehicles has been the subject of growing interest over the last few years, motivated by the recent technological advances in the fields of MAV applications. The main objective of this paper is to overview the MAVs multidimensional flight characteristics to deport the human vision beyond the natural horizon, in order to accomplish risky missions in the place of humans and in confined environments.

MAV's are yet another example of how technology is aiding humans in performing dangerous tasks, allowing the humans to stay out of harm's way. Intelligence, Surveillance and Reconnaissance (ISR) missions, searching for earthquake victims and traveling to other worlds are all hazardous activities. MAVs would allow us to accomplish these tasks without actually being there.

All indications are that these systems can be developed with today's emerging electronic and related technologies. If this is so, we may optimistically anticipate a rapid evolution of MAVs to militarily useful and flexible systems in the not-too-distant future.

VII. References

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VIII. Acknowledgment

First of all I would like to thank Almighty God by the grace of whom I reached the stage of completion of this work. With a deep sense of gratitude, I express my indebtedness to my reverend guide Prof. Rajendra. R. Patil for his worthy advice, commendable guidance, inspiration and encouragement which were the sources of energy throughout this work. Without his guidance it would have been difficult for me to understand the wide spectrum of information detailing required in this work.

This avenue has been a turning point in my career to mould me into professional. My sincere thanks to the President Poojya Dr. Sharanabaswappa Appa, Dean of administration Dr. Anil Kumar G. Bidve, and Principal Dr. V.D Mytri of my esteemed Institution, Appa Institute of Engineering and Technology. I am also thankful to my beloved parents who have helped me pave this path to success.