MICRO AIR VEHICLES IN INDIA - AN OVERVIEW

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Abstract

The genesis of the Micro Air Vehicles (MICAV) program and its progress in the last decade is discussed. Fixed, rotary and flapping wing MICAVs (300 mm class) have been successfully flown using remote control by Educational Institutions, Laboratories and enthusiastic entrepreneurs, transmitting video imagery. They are now moving on to autonomous control and its integration with navigation and guidance. The need for micro-sensors has led to work on convergence of micro, nano, bio, info and cogno technologies which are discussed. The need for simulation and cooperative flying of MICAVs with UGVs is stressed and finally the thrust areas for the next five years have been suggested for aerodynamics, structures, control, navigation, guidance, sensors (including bio sensors), power sources, simulation and operations involving brain-machine interface.

Introduction

Research and Development work in India on mini and micro air vehicles was initiated at a meeting of the Aeronautical Society of India at Hyderabad in March 1998. The first group to take up this challenge was the Department of Aeronautics at the Indian Institute of Science (IISc) followed by National Aerospace Laboratories (NAL), Indian Institute of Technology (IIT) Bombay and the National Design and Research Forum (NDRF) of the Institution of Engineers (India). An MAV workshop was organized at Madras Institute of Technology in 1999 covering fixed wing, rotary wing and flapping wing MAVs. Based on the discussions, the participants set a target for an MAV of 400 gm with a payload capacity of 40 gm - a goal which seemed difficult to many at the time. A task team identified the various areas for R&D in MAVs. By 2004 it was decided that MAVs of the class of 750 to 1500 mm can be handled by industry. R&D groups were requested to concentrate on Micro Air Vehicles (MICAVs) limited to a maximum dimension of 300 mm and this remains our current goal.

MAVs can be utilized very effectively in

- Disaster management (Fire, floods, earthquakes, landslides, gas leaks, search and rescue)
- Defence / Security (Surveillance, Reconnaissance, communication relay, electronic warfare, mine/NBC detection, riot and traffic control, crowd monitoring)
- Commercial (Agricultural, Photography, Television, Cinema)
- R&D (Evaluation of new concepts)

An Indo-US workshop on Micro Air Vehicles was held at NAL in 2006 with participants from USA, India, Australia and Europe. The first National Flying Competition for MICAVs in 2007 at Agra was sponsored by DRDO and organized by Aeronautical Delivery Research and Development Establishment (ADRDE) and NAL. It attracted 16 teams covering fixed wing, rotary wing and flapping wing categories and provided a tremendous impetus to MAV activities in India. All the MAVs were less than 400 gms.

This was followed by (MAV-08), an International meet - "1st US- Asian Demonstration and Assessment of Micro Air Vehicle and Unmanned Ground Vehicle Technology" sponsored by the US Army, with the US Navy and Air Force as Co-sponsors. DRDO, CSIR and the Government of Uttar Pradesh supported the event from India. The programme organized by the US Army, NAL and ADRDE had the "Identification of hostages and their rescue" within 40 minutes as the mission objective. Teams from Australia, France, Germany, Japan, Holland, India, Spain and USA participated and put in excellent effort resulting in an overall performance which the international panel of judges assessed as being very creditable. The entry of IIT (Bombay) was adjudged the best in the rotary wing category. A series of lectures by experts in special

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areas were of great topical interest. Finally, the users (Army, Navy and Air Force) also indicated their expectations from MICAVs.

Aeronautical Development Establishment (ADE), National Aerospace Laboratories (NAL) and Air Force Research Laboratory (AFRL), USA organized a workshop in November 2008 at Bangalore focused on the science aspects (including biology) of MICAVs. Currently ADE and NAL are engaged in the development of a rugged (300 mm) MICAV.

The areas of prime interest to MICAVs are indicated in this paper.

Aerodynamics

Low Reynolds number flows are characteristic of MICAVs as shown in Fig.1. Unsteady aerodynamics and response to gusts are critical. 3D Navier-Stokes formulations are being evolved. Studies in insect aerodynamics, microfluids and Coanda effects, both theoretical and experimental, are in progress. Theoretical results (including CFD) must be correlated as much as possible with experiments from flow visualization and wind tunnels. It is essential to set up the necessary facilities.

Structures

Structures can be multifunctional structures, smart structures, flexible structures and adaptive airfoils.

Biological systems outperform, in every aspect, small manmade aircraft. Direct mimicry of flapping motion is very challenging (Fig.2). Thin, under cambered 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. Fixed, flexible wings can provide a practical platform for MICAVs driven by propellers.

Materials - Balsa, low density composite and carbon nanotubes.

Adaptive airfoils considering aeroelasticity adapt better to gusts. Thin films over stiff ribs can be used while rigid leading edges gave better lift. Researchers have used

- 1 mm dia carbon fibre frame and mylar
- MEMS technology
- Variable density/stiffness material (eg Squids).

Table-1 : Multifunctional materials concepts

Concept	Mass	Aerodynamic Shape	Remarks
1	Constant	Constant	Structure packages battery
2	Variable	Constant	Part of structure is fuel
3	Variable	Variable	Structure inflatted by fuel

Multifunctional Materials concepts are given in Table-1.

Multifunctional concepts combining structures, power and actuator functions are also being explored.

Propulsion

Propulsion is a key element. Propellers driven by DC micromotors (Nd-Fe-B) are most popular. The power sources can be Batteries (Li-ion), fuel cells or microwave. Research to improve efficiency of the propellers is required. A micro pulse jet is another option. Digital propulsion with microthrusters using solid or liquid propellant to accelerate or change direction is promising. Micro fluidics is required to model flow of liquid propellants and gases through micro channels.

Reciprocating Chemical Muscle (RCM) stems from Biology.

- Wasp Muscles - Move 2 % of overall muscle length.
- Gases can be used for actuation of flapping airfoils.
- Shape memory alloy "muscles" compare with dragon flies flapping at 20 Hz.
- Electro Active Polymer (EAP) gels e.g. Polyvinyl Alcohol-Poly Acrylic Acid (PVA-PAA) expand and contract under electric fields, simulating muscle action.

Stabilization

Robust autonomous stabilization is critical for all MICAVs.

- Reference for stabilization

- Inertial sensors-MEMS gyros and accelerometers.

- Vision based stability (Fig.3), utilizes texture difference between ground and sky from pixel array data for horizon detection. Kalman filter improves estimates.

- Forces - conventional control surfaces and discrete actuators, distributed microflaps, and Warping of lifting surfaces. Smart materials can be used.

- Actuators - Micromotors, Piezoelectric actuators and microfludic elements. MEMS arrays based on electromagnetic, electrostatic, piezoelectric and ultrasonic responses.

Control

- Design can be based on flight control systems developed for UAVs

  - Manual (Remote Control),
  - Semi autonomous - Manual take off and landing
  - Fully autonomous

- Control forces - As for stabilization
- Swarm Control for teams of MAVs (Fig.4)
- Adaptive Wings and unsteady Aerodynamics

- Highly non-linear, time variant. Fuzzy logic and neural network controllers are required

Navigation

It may be magnetic, MEMS based with GPS or vision based as indicated.

Magnetic Heading	- Short duration
INS-MEMS gyros and acceleration	- Moderate duration
GPS	- Longer duration
Vision	- Terminal
IMU-GPS-Vision	- Caters for loss of GPS
Kalman filtering of sensor data	- Reduces errors from lower grade inertial
Fractal antenna	- Reduces weight

Guidance

Guidance Schemes can be based on

- Current position and required target
- Recognition of way points
- Homing on to source of any electromagnetic radiation

Collision avoidance schemes have used

- Ultra Wide Band Radar C Band (50 gms)

Peak Power (mW) : 25, 800

Detection Range (m) : 20, 250

Optic Flow (Visual motion) is a Biomimetic concept. It is the apparent movement of textures in the visual field due to the motion of the flying object (Fig. 5).

- Faster the flow in downward direction - Lower the height
- Rapid expansion in forward direction - Closer the obstacle

Integrated Control-Navigation-Guidance

The aim is to have one subsystem which will integrate

Autopilot
IMU-GPS
Vision

Homing	- Acoustic	- Nuclear radiation
	- Electromagnetic	- Biological toxins
	- Chemical	- Olfaction

Sensors

MICAVs need micro-sensors to perform their missions effectively. The main sensors are given in Table-2.

Table-2 : Micro sensors for MICAVs

Micro Sensor	Technology
Imaging	Vision Chips
	Micro-bolometer arrays
Pressure	MEMS
Force	MEMS
Flow	CNT, (Prof Ajay Sood, IISc)
Taste	Artificial Tongue
Odour	Artificial Nose, Bio Sensors
Acoustic	MEMS
Pathogens	Biosensors
Pesticides, Poisons	Chemical Sensors
Electro-magnetic	RF MEMS
Vacuum	MEMS
Controlled atmosphere	Chemical/Pressure Sensor
Radiation	Ultra Pure Silicon Chip
Explosives	Coated CNT, MEMS, Bio sensors

Realization of these micro-sensors requires the convergence of micro, nano, bio, info and cogno technologies as indicated in Fig.6. All these technologies are complementary. A technology mix/options for MICAVs is suggested in Fig.7.

Biosensors

Biosensors are promising for MICAVs for some of the missions by integrating Biology and Engineering as indicated in Figs.8 and 9. Biological and artificial olfactory systems are compared in Fig.10.

Insect Sensors

As MICAVs become smaller, insect sensor concepts are promising. Insect sensors used for navigation and vision are indicated below :

- Halteres - Small Structures protruding from thorax and perturbations due to rotation picked up by tiny hairs which act as inertial sensors to detect fast rotations
- Compound Eyes have multiple lenses for wider field of view.
- Ocelli are small, simple eyes which sense horizon for flight stabilization.

Light Sensitive proteins are used for image sensing and their spectral responses are shown in Fig.11. Shifting of response peaks using conducting polymer is shown in Fig.12.

Power Sources

Major constraint is weight

- Batteries - Li Ion, Li Polymer
- Fuel Cells - Methanol
- Micro-gas turbines
- Super capacitors - Very high discharge rate
- Solar cell - trickle charging other systems on ground
- Adenosine Tri Phosphate (ATP)

Lithium Polymer Battery electrode using nanosize particles given increased power (Table-3).

Table-3

Sl. No.	**Parameters**	**Conventional Li Ion**	**Using Nano Li-Tio2 particles**
1	Power	P	3P
2	Recharge	Hours	Minutes
3	Cycles	100s	1000s

Simulation

Digital, virtual reality and hardware-in-loop simulations are extremely useful. Fig.13 shows a flapping wing MICAV in flight and simulation of this class of vehicle will be a challenge. Fig.14 indicates a scheme for simulation of signal integrity.

Operations

- Mission Planning
- Swarms
- Recovery of MICAVs

Cooperative Flying of MICAVs with Unmanned mini Ground Vehicles (UGV) will be very useful in some missions. Fig.15 shows a 300 mm MICAV after launch from a mini Unmanned Ground Vehicle.

Overall Summary

MAV activity is summarized in Fig.16 indicating the thrust areas for the next 5 years.

Fig.3 Vision based stability

Fig.1 Effects of low Reynolds number

Fig.2 Biological inspiration

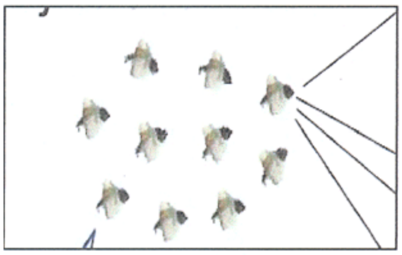

Fig.4 MAV swarm (with sensors)

Fig.5 Optical flow for visual navigation and guidance

Fig.6 Convergence of technologies for MICAV applications

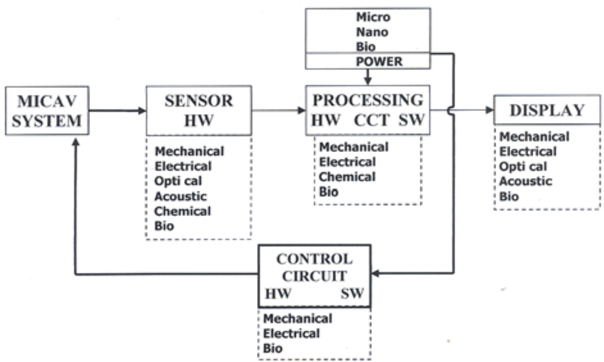

Fig.7 MICAV system - technology mix/options

BIOLOGICAL MATERIAL		+	TRANSDUCING MICROSYSTEM	
- Tissue	- Enzymes		- Optical	- Piezoelectric
- Microorganisms	- Antibodies		- Electrochemical	- Magnetic
- Organelles	- Nucleic acids		- Thermometric	
- Cell receptors				

Fig.8 Integration of biology and engineering for biosensors

Fig.9 applications and schematic of biosensors for MICAVS

	Olfactory System (Sniffer)	
Step	**Biological**	**Artificial**
1. Acquisition of Vapour phase molecules	Muscular Diaphragm Inhalation	Sniff Pump
2. Interaction with Sensing materials	Nasal Cavity	Sensor Head
3. Transduction (Converting molecular information to electrical)	Olfactory Receptors	Polymer Sensor
4. Transmission to analyzer	Neuronal	Electrical
5. Information Decoding and recognition	Olfactory bulb and cortices	Computer Chip
6. Out put	Biological reaction	Control circuit and display
7. Storage	Brain	Computer memory

Fig.10 Comparison of biological and artificial Olfactory systems

Fig.11 Spectral response of photocurrent from indigenous bacteriorhodopsin flim

Fig.12 Spectral response : bR on conducting polymer

Fig.13 Flapping wing MICAV (300 mm)

Fig.14 Simulation of signal integrity

Fig.15 Launch of MICAV from UGV (Drone and DC Enterprises)

Fig.16 MICAV activities in India