

Micro Robotics

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Week-10

Lecture-49

Microsystem for Microrobotics (Integrated approach) - Module 04

We want to discuss micro-assembly. We have already discussed the various aspects of microassembly, especially related to the influence of scaling loss. We have also discussed the different sources and applications of these microassemblies. The electrostatic forces are involved in the appropriate configurations of these microassemblies. Overall capillary interaction of these micro-assemblies, the role of magnetic and micro-assemblies, comparison between direct assembly versus traditional assembly, and how these have been deployed are also discussed along with some case studies related to this micro manipulation. Further, some discussion about the different challenges that are involved in microassembly is needed.

In today's lecture, we will discuss these micro aerial vehicles. These micro aerial vehicles are of concern, especially micro drones. These micro drones have potential applications in defense. In fact, they are involved in the inspection of tubes, pipelines, AC ducts, etc. in detail. When we try to define micro aerial vehicles, which are small, unmanned aircraft designed for reconnaissance and surveillance, the overall size of these micro aerial vehicles is typically from a few centimeters to around 50 centimeters and they can be controlled remotely or autonomously. These micro aerial vehicles are widely used in defense-related fields, especially in strategy-related areas, commercial applications, and research applications. It is mainly due to their agility and ability to operate in confined spaces, as we might have heard a lot about these micro aerial drones, etc. They can work in a confined space, and appropriately, they can give input to the system, or they can capture the required functionalities for different strategic-related applications.

In fact, it has a wider spectrum. So, micro aerial-based electronic systems and micro aerial-based structures are there to be appropriately deployed. In the case of these micro aerial vehicles, one of the key elements is the wings. When we discussed a drone, we have a fan-like structure; when the fan rotates, you can appropriately see the motion. Whereas in the case of a wing, the flapping wing of the micro aerial vehicle, these wings flap at a very

high frequency, and based on the frequency, we can appropriately use it for different requirements or applications.

When we try to look into the overall definition of this flapping, the flapping or beating motion of wings is exclusively used in the powered flight of a bird. I have integrated two similar GIF files over here, which basically explain how a flapping wing can be helpful for appropriate aerodynamic motion. They are meant to power the flight of birds and insects to counter the force of gravity and propel themselves against aerodynamic drag. So when we try to quantify such flapping, the mode and the frequency of the flapping motion differ among the different species and are strongly dependent on body size, shape, and flight mode. They are always selected for optimal power consumption in the respective flight modes.

The difference between the flapping motion of a bird and that of an insect is in the way they use aerodynamic forces for lifting and drag. Based on the lift and drag, we can establish a flapping motion of the bird. So, especially in the case of birds, we can consider the Reynolds number. The Reynolds number, which is the ratio of the inertial force to the viscous force, and the wings' aspect ratio are so large that they deliberately use their wings to sustain their weight by lift. So, with a large wingspan and high aspect ratio, they can achieve long-range flights.

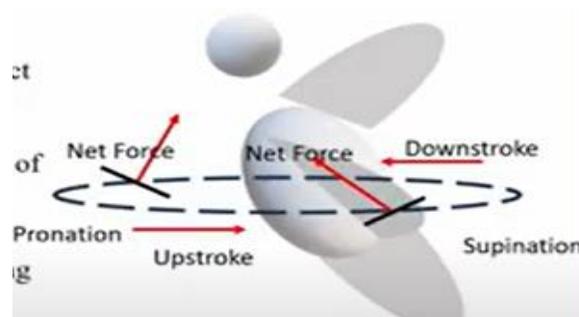


It is one of the key aspects of these micro assembly robots. Now, if we are trying to design such kinds of micro aerial structures or micro aerial robots, some of the key parameters that we may need to investigate include a type of flapping wing MAV. In this, the Reynolds number and the aspect ratio are too small to provide the necessary lift. Now, if we try to investigate the different process parameters that are available, like the net force, then we have the downstroke. So, this is a kind of moment of the flapping MAV.

In this flapping MAV, we have two net forces. One net force is in this particular direction, and the other is along the median of that direction, and then there is a downstroke. So, in this downstroke, there will be a moment. In this particular case, there are two sets of motions: one is called pronation motion, and the other is called supination. These are considered to be the different motions exhibited in the case of a flapping wing of a MAV system.

In insects, let us consider the earlier case when we try to look at the Reynolds number. The Reynolds number, which is different from a bird's perspective point of view, is also different from an insect's point of view. So in the case of an insect, the Reynolds number and the aspect ratio are too small to provide the necessary difference, but they owe much of their extraordinary evolutionary success to flight. Their survival and evolution depend on flight performance, different flight-related sensors, psychological behavior, and biomechanical traits. So these are some of the key aspects that we may need to consider.

The flapping motion of an insect can be divided into three separate motions. One is called a sweeping or a flapping motion. Sweeping or flapping is a forward and backward movement of the wings. Heaving is an up-and-down movement, and pitching is a change in the incidence angle. Now, let us see this figure. This figure is a schematic representation of the left wing motion of an insect left-wing complete flap cycle for a sophisticated insect wing motion consists of two translations, which are a downward stroke and an upstroke, and two rotations. So basically, these are named pronation's at the end of the downstroke and supinations at the end of the upstroke. So this is a kind of pronation that is scattering the upstroke and the supination at the end of the downstroke. So during the translation, the wing may show a kind of sweeping, heaving, and pitching motion.



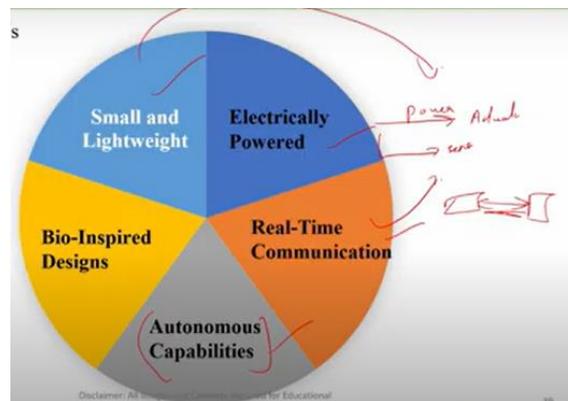
In addition, at the end of the half stroke, during the stroke reversal, the wing pitches rapidly, and the exact wing kinematics vary among the different insects for different motions. So that is how we introduce the parameters of pronation and supination, which are key parameters for designing any kind of system. In this case, insects have generated great interest among biologists and engineers because of their biomimicking capability. Because at first, flight seems improbable using standard aerodynamic theory. We have observed that in most cases they don't follow the aerodynamic theory.

However, when stabilization occurs, aerodynamic theories are established. So the combination of small size, high stroke frequency, and a particular reciprocal flapping motion of the insect makes its flight aerodynamic. So, if we closely observe these micro

aerial vehicles, they are small unmanned aerial vehicles of size less than 50 centimeters. So, now the sensor and actuator should be within that particular domain, and the entire feedback system should be within that particular domain. Hence, we can develop a small onboard chip accordingly. In this particular case, these MAVs are not smaller versions of larger aircraft. They should be seen as a kind of aerial robot having more degrees of freedom and agility than regular aircraft. Actually, it is something like having more degrees of freedom. Hence, we can have an improvement in agility, and then it acts as a kind of regular aircraft. The disturbances or noises that are generated can be countered owing to their agility as well as with reference to the flapping characteristics.



Now, when we try to look into the features of MAVs, an important feature is that they are small and lightweight. So when we are trying to use such a kind of aerodynamic structure for movement, it is expected that the system should be small and lightweight. An important point with reference to these MAVs is that they should be electrically powered. So when you try to power up, you can see motion. Then it will be a bio-inspired design.



In the bio-inspired design, it discusses more about its capability in such a way that there will be a kind of flapping behavior, which exists owing to its flapping behavior. Hence, appropriately, we can expect motion. Then we have real-time communication. In real-time communication, we can consider today's drone technology, especially when talking about micro aerial vehicles for an arrangement or for conditions; such kinds of real-time

communications are required so that they can start communicating with each other. For an appropriate motion, one of the important capabilities is the autonomous capability.

In some cases, they may need to work in a group, or in some cases, they may need to take a swim. In some cases, they should have autonomous capabilities in such a way that their feedback can move in an appropriate direction so that they can have motion. When you try to closely observe these features, they play a vital role in the development of the system. Especially if I try to converge this powering, it will cater to the actuator and the sensor. It has direct relevance to the power capability. In real-time communication, communication happens between two different entities. So appropriately, you can have a kind of movement, and then there are a kind of autonomous capabilities. In these autonomous capabilities, it is something like when a system is integrated, it has its own decisions. Whenever it has its own memory capability, it can capture its own decisions for appropriate movements or appropriate motions, etc. Now, from a bio-inspired design perspective, it is as if once you try to get the design from a biological point of view, it has its own challenges in implementation.

However, with reference to functionality, it is already an approved system. So, by implementing it we can have an appropriate ease in motion as well as a flexibility in the overall process. Now, let us discuss the different types of this micro aerial vehicle. Based on the different types of micro aerial vehicles, we can classify these micro aerial vehicles into three categories. One is a fixed-wing micro aerial vehicle, another is a rotary-wing micro aerial vehicle, and the third is a flapping-wing micro aerial vehicle.



The entire classification of this micro aerial vehicle depends on the overall capability, especially the overall movement as well as the overall wing capability. In some cases, we have a fixed-wing type; in some cases, we can have a rotary type; or in some cases, we can have a flapping wing type. Now, on fixed-wing type, these fixed-wing micro aerial vehicles, also known as micro drones, may be defined as micro aircraft capable of completing surveillance or recognition missions in outdoor or indoor environments. So this is one of the key aspects with respect to fixed-design micro aerial vehicles. So this is a fixed-design micro aerial vehicle.

It is a kind of micro drone. It almost looks like an aircraft, and it is used for a wider range of applications. In this particular case, the wing design is crucial, with factors like platform, aspect ratio, and camber influencing the aerodynamic performance. So when we try to look

into the overall wing design, it has to withstand both the drag and the lift. Appropriately, the ratios are maintained. Now, in this particular micro aerial vehicle, propellers are commonly used.

So for thrust generation, the interaction between the propellers and wings can enhance lift and stability, especially in configurations with counter-rotating propellers. So when there are propellers that exhibit the motion of the propeller, we can observe lift and stability, and then a kind of counter-rotating propellers. In most cases, it is used in mapping, surveillance, and disaster response when it is required. So these are some of the major characteristics with respect to fixed-wing micro aerial vehicles. Now, the second type, which is called a rotary-wing micro aerial vehicle.



In this rotary-wing micro aerial vehicle, we have rotors in place. Rotary wing micro aerial vehicles are small; they are unmanned aerial vehicles that use rotor blades to generate lift and propulsion. They are particularly useful for missions requiring hovering maneuverability and in tight spaces, as well as vertical takeoff and landing capabilities. Ideally, this is used for vertical takeoff and landing, such as VTOL capabilities, etc. In most of these cases, these systems are kind of a radio-controlled 4-rotor aerial vehicle with 4 channels of input to control the motion of the micro aerial vehicle.

It depends on where we want to have a varying speed of the 4 rotor; the motion can be appropriately controlled. So in this particular case, we have 1, 2, 3, and 4, so 4 propellers are there; propellers 1 and 3 and 2 and 4 turn in the opposite direction. So it is like controlling each of these propellers individually; we can have control over the overall flight motion as well as control over the overall movement of the system. So, the rotors turn in the opposite direction, which removes the need for a tail rotor. For torque compensation purposes, it makes the helicopter a lot more compact.

The rotor turns in the opposite direction. This will help with the rotor movement. Typically, a coaxial micro aerial vehicle uses the residual torque due to the angular speed difference between the two rotors to rotate the helicopter vertically left or right. Increasing or decreasing the angular speed of the rotor simultaneously permits climbing and descending. So these are some kinds of micro drones that are seen in several applications and several systems. Individually controlling such rotors will help us have control over the angular speed as well as control over the vertical moment.

Now the third type is a flapping type, which we have discussed earlier. In this flapping type, it is more difficult to handle the up and down motion. Wherever we have a higher frequency, we can have a movement that exhibits over there. Now, let us discuss some of the key characteristics of this micro assembly. When we try to quantify these micro aerial vehicles, we can quantify them with reference to both the kinematic frames and the dynamic frames.

Kinematics Frames

Dynamics Equations of Motion

MAV System Description

- Consider O_i and CM are two points located on the rigid body.
- $S_{oi,cm} \in R^3$ is the vector that joins extreme border O_i with rigid body's center of mass.
- V and ω are translational and angular velocities respectively at any point in the R^3 .
- f and τ are forces at any point in the R^3 .
- The kinematic transformation equation for Dragan Flyer body is given as,

$$\dot{V} = \begin{bmatrix} \dot{\omega}_{cm} \\ \dot{v}_{cm} \end{bmatrix} = I_{cm,\tau}^{-1} [F_{cm,\tau} - I_{cm,\tau} V_{cm}]$$

$$\dot{V} = \begin{bmatrix} J_{cm,\tau} & -S_{oi,cm}^s m_T S_{oi,cm}^s & m_T S_{oi,cm}^s \\ -m_T S_{oi,cm}^s & m_T U \end{bmatrix}^{-1} \begin{bmatrix} \tau_{cm,\tau} - \tilde{\omega}_{cm} J_{cm,\tau} \tilde{\omega}_{cm} \\ f_{cm,\tau} \end{bmatrix}$$

$J_{cm,\tau}$ is the total inertia of the vehicle due to rotors and electronics with total mass m_T .
 U is the identity operator.

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So, with reference to the kinematic frames, we try to incorporate the movement, and in dynamic frames, we try to incorporate the movement. In the case of a kinematic frame, we may need to solve the kinematics to get the overall description, such as rigid body dynamics, as well as the overall system description. Hence, discuss the kinematic frame, the dynamic frame, and the overall flapping wing-based micro aerial vehicles with reference to their performance in detail in the next lecture. Thank you.