Can robots teach us about animal flight?

Animal flight has fascinated people since eternity. Birds, bats and insects all perform breath-taking aerobatic manoeuvres when perching on a wind-swayed tree branch, following a swarm or escaping a predator. Yet, scientists remain puzzled about how the animals control these manoeuvres and what sensory systems they use.

Insights into animal flight control are of great interest not only for biologists, but also for designers of bio-inspired flying robots. The common approach in animal flight research is to record the animals while manoeuvring with high speed cameras. The footage is processed to reconstruct the motion of the animal as well as of its flapping wings. Subsequent analysis can reveal how the changes in wing motion patterns translate into the body accelerations. However, without looking into the brain of the animal (which is currently possible only when the animal is tethered) scientists can only hypothesize what the underlying control processes are. In our research, we wanted to show that such hypotheses can be tested with a free-flying animal-like robot. A programmable robot allows any control algorithm to be implemented and, unlike in animals, systematic tests can be carried out. Moreover, all the sensory signals, internal states, and control signals are available, which can bring further insights into the flight manoeuvre dynamics.

We have been developing bio-inspired flying robots within the DelFly project for over a decade and our latest design, the DelFly Nimble, brought us the closest we ever were to the flight capabilities of a winged insect. Our robot with four flapping wings can hover in mid-air, climb, descend and fly in any direction, with very agile transitions from one flight mode to another. Its palm-sized wings beat 17 times per second, providing enough lift force to support its weight. The body orientation is controlled by adjusting the motion of the wings like in insects, and also the sensors and algorithms used onboard to stabilize the flight are similar to what is believed insects use. Despite a much larger size and a different wing arrangement compared to real insects, the motions of the robot in flight greatly resemble those seen in nature.

The robot's high agility allowed to test whether we can "replay" the escape manoeuvres of fruit flies. Flies perform these rapid banked turns when evading danger, e.g. when a human hand is trying to swat them. They maximize the escape performance by pointing the thrust vector of their flapping wings away from the threat. To do that, they rotate their body simultaneously around the forward (tail-to-nose) and lateral (wing-to-wing) axes, since the thrust vector direction remains fixed with respect to the body. This happens so fast, that, to our knowledge, the initial rotation cannot be picked up by its sensory systems. Thus, in previous research, Muijres et al. hypothesized that this initial rotation is performed in *feed forward*: The fly would adjust the wing motions according to an internal model, which predicts the resultant body motion. The fly's sensory systems would only be used later to recover from the high bank and restore stability.

We have programmed such control actions into the robot and indeed we could observe banked turns closely resembling those recorded in flies. However, during the recovery, both in the robot as well as in flies, we observed a rotation around the third, vertical body axis. Since we were in full control of the robot and no such rotation was commanded, we were certain this must have been a result of some passive aerodynamic effect. Thanks to the full knowledge of the robot's states we were able to describe this newly discovered effect with a relatively simple mathematical model. We termed it *Translation-induced Coupling Torque*, as it is a coupling effect between the body translation and the wing motion changes introduced to recover from the turn. We have shown this effect is likely present in fruit flies, but we beleive it might be present in all flapping wing fliers when performing complex aerial manoeuvres.

By conducting experiments with an insect-like free-flying robot, we were able to provide strong support for the existing hypothesis on how fruit-flies control escape manoeuvres. Moreover, the knowledge of the robot’s internal and external states allowed to discover and describe an aerodynamic mechanism helping the flies in performing such sharp turns. We believe using bio-inspired robots is a promising research line which will bring further insights into the complexities of animal flight. At the same time, the insights gained should help us develop better bio-inspired flying robots, which in comparison to traditional drone designs promise higher agility, power-efficient forward flight and potential for further miniaturisation.