The ROBUR project: towards an autonomous flapping-wing animat

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Abstract

Flapping-wing flight is not applicable to huge aircrafts, but has a great potential for micro UAVs - as demonstrated by real birds, bats or flying insects. The ROBUR project aims at designing a robotic platform that will serve to better understand the design constraints that this flying mode entails, and to assess its capacity to foster autonomy and adaptation. The article describes the major components of the project, the tools that it will call upon, and its current state of achievement.

1 Introduction

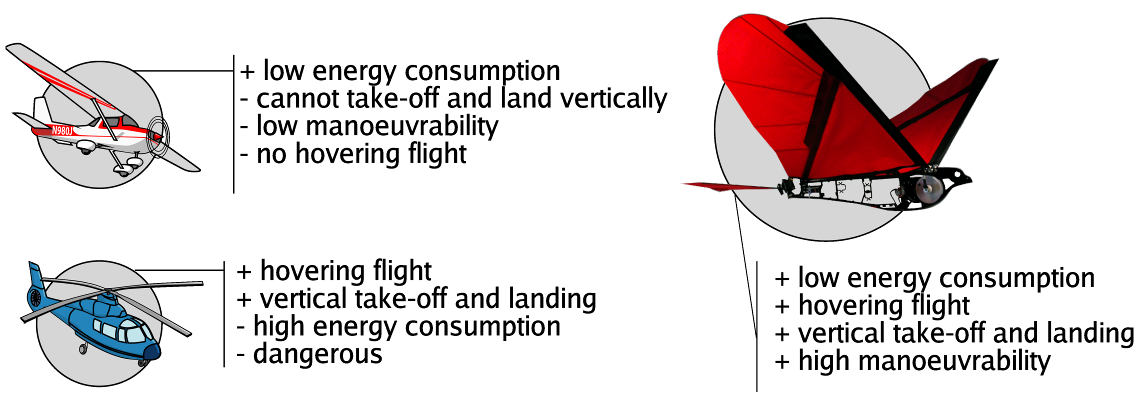

Figure 1: Aircraft with fixed, rotary or flapping wings.

Mini and micro UAVs have raised increasing interest in recent years. The physics underlying this kind of platform has been the subject of numerous studies and our knowledge on this question has made significant progress. However, at the same time, few studies have focused on the embedded intelligence of such platforms.

If ground robots are now endowed with advanced autonomous abilities - allowing them to avoid obstacles, to build internal maps of their environment [5, 8], to choose the best action to undertake at any time [6] - their flying equivalents are far from exhibiting such abilities, and a direct application of techniques developed for ground robots is impossible for several reasons.

First of all, the range of available sensors that may be fitted to small flying aircrafts is more restricted than for ground robots. Indeed, ultrasonic range sensors can hardly be used for size and energy consumption reasons. Likewise, infrared sensors are very sensitive to external light, and laser sensors are both heavy and dangerous. As a consequence, micro UAV can hardly estimate the distance of surrounding obstacles, a limitation that prevents the use of classic obstacle-avoidance techniques.

But this limitation is not the only one. Ground robotics techniques often exploit hypotheses that are not valid for aerial robots. Cartography algorithms, for instance, are often designed for indoor robots and exploit knowledge about environmental specificities - such as straight walls or right angle corners - to increase precision. Usually, such hypotheses cannot be made for outdoor experiments. Furthermore, a camera on top of a ground robot remains at a constant height. Perceptions are thus quite stable and reproducible : when the robot gets back to a given place, it acquires similar perceptual data, thus simplifying the localization task. Again, this is not possible when the altitude of a flying robot is always changing. Therefore, new and more robust techniques have to be developed to allow a flying robot to build a map of its environment.

The ROBUR project aims at studying these issues, which are essential prerequisites for robot autonomy, within the context of a flying robot in general and of a flapping-wing robot in particular.

2 Presentation

The project has two main objectives. The first one consists in better understanding bird's biology, biomechanics, neurophysiology and ethology thanks to the integrative approach that the design of artificial artefacts imposes. The second one concerns flapping-wing UAV design, whose flying mode exhibits distinctive features relative to other aircraft (figure 1) that make them promising for numerous applications, either civilian (communication relay, farmland monitoring, building inspection) or military (surveillance, exploration).

For many of these applications, usual UAVs - with fixed wings (airplanes) or rotary wings (helicopters) - suffer from drawbacks related to their flying mode: airplanes can't hover and helicopters consume great amounts of energy. On the contrary, flapping-wing aircraft share the advantages of these platforms without their drawbacks. They are hardly detectable as they look like real birds, and they are much less dangerous than classic aircraft. This platform is accordingly more promising, its potential is clearly demonstrated in nature by the omnipresence of birds, bats and flying insects in varied environments.

The project is composed of four main sub-problems, which will be first studied in simulation and independently from one another, before the corresponding results are integrated and applied to real platforms. These sub-problems concern respectively:

- Maneuverability of flapping flight
- Dynamical transitions
- Energy saving
- UAV sensorimotor apparatus

Depending on the specific issues that will be tackled, the corresponding solutions will draw inspiration from different bird species. For instance, researches on energy sparing will call upon current knowledge of the gliding behavior of sea birds, while those on maneuverability will be derived from the physiology and ethology of birds of prey. Likewise, neurophysiologic data acquired on owls could be used for designing neural controllers.

2.1 Research on flapping flight maneuverability

A generic model of a flapping wing aircraft has been designed, in which lifting surfaces are modelled by a set of articulated panels (figure 2). In a first stage, this model will be used to design a simple periodic controller for such a platform by using evolutionary algorithms (figure 3). This controller is expected to generate a periodic, horizontal, flapping flight at a constant speed.

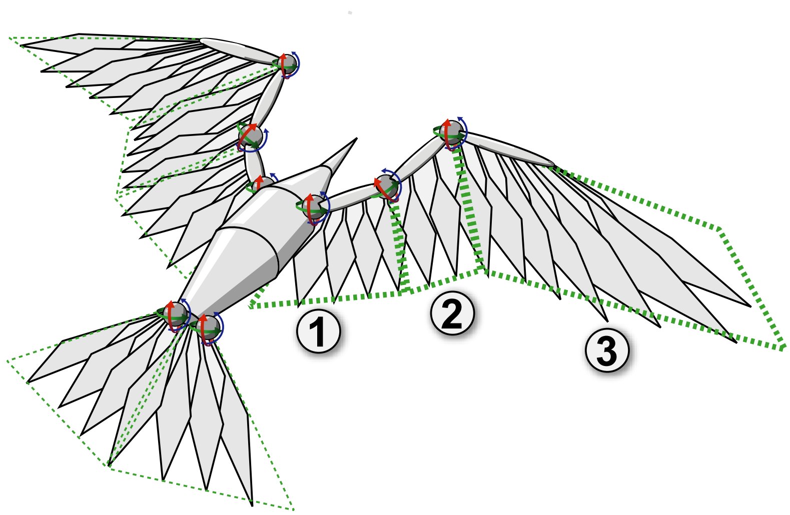

Figure 2: Physical model used in this project.

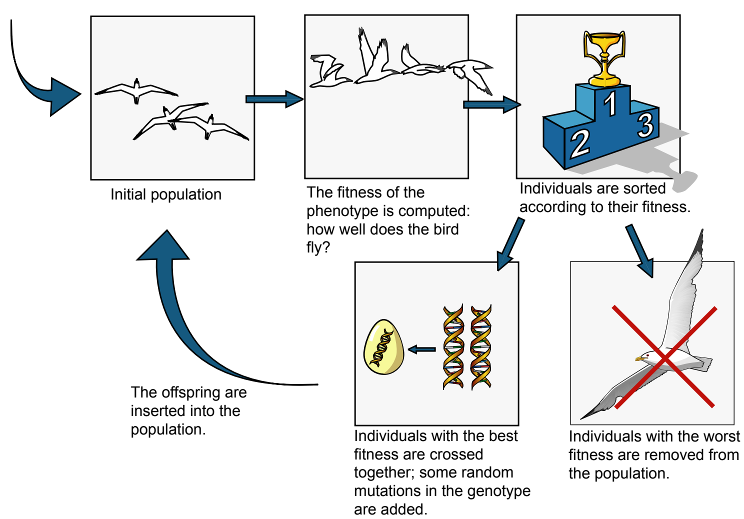

Figure 3: Design and optimization of a periodic controller with artificial evolution.

The knowledge thus acquired will then be exploited to generate controllers for artificial birds whose anatomy will be systematically varied : shape and weight of the body, wing features (building materials: flexible or stiff; panel numbers; inter-panel articulations: active or passive), number and characteristics of effectors generating wing or tail movements. The goal will be to study different possible morphologies while evaluating their performances according to maneuverability and energy consumption criteria. An evolutionary approach will be used for this purpose.

Several of the corresponding simulated aircraft will be used to build real platforms which will be used to validate the simulator through the comparison of theoretical and real force measurements.

2.2 Research on dynamical transitions

The former study will later be extended to the generation of controllers that will make transitions possible between hovering and forward flight, on the one hand, and between take-off or landing and cruising flight, on the other hand. Two varieties of evolutionary approach will be used to this end. The first one will directly evolve individuals able to exhibit both behaviors. The second one will proceed in an incremental way, first generating specialists of the first behavior, and then adapting them so that they become able to appropriately switch towards the second behavior. The latter approach has been successfully used at the AnimatLab to evolve a neural network able to first control the walking behavior of an hexapod robot, and then to also control obstacle-avoidance and gradient-following behaviors [7]. Still another possible approach to the dynamical transitions issue will be to study the opportunity of providing some bootstrapping knowledge to the evolutionary process, in the form of neural modules exhibiting predefined functionalities [3]. Such predefined modules could implement oscillators or fuzzy switches, for instance.

2.3 Research on energy saving

Several studies may be undertaken at different levels. We may first add a criterion evaluating energy consumption in the optimization process of the controllers. Evolved controllers would then directly take this criterion into account. In their simplest versions, the corresponding controllers should prove to be able to inhibit wing beats whenever possible, i.e., when the artificial bird can exploit the wind or when it deliberately chooses to go down.

At a higher integration level, more elaborate navigation strategies - exploiting, for instance, memory or anticipation capacities - will also be implemented, thanks to which a flying robot would explore its environment, build a cognitive map of it, and use this map to plan trajectories exploiting thermal or ridge soaring (figure 4) or aiming at a refilling station for instance. To this end, specific research efforts will be dedicated to landmark extraction and recognition from aerial views. The corresponding algorithms should be robust to rotation, contraction or expansion effects, because landmarks will be seen from different altitudes and angles.

2.4 Research on UAV sensorimotor equipment

The UAVs that the ROBUR project will produce will be equipped with at least visual and inertial sensors. Other sensors, like artificial cochleas or sonars, could be implemented on these platforms, drawing inspiration from owls or bats, for instance. Several research efforts will be devoted to optic flow management, because the translational component of this flow provides information about the distances to surrounding obstacles (figure 5 left) or about the time to contact (figure 5 right). This information may thus be exploited to implement obstacle-avoidance strategies.

Other capacities - like take-off or landing control, or trim control - may also exploit it. Such applications will raise interesting issues related to sensor fusion, because they will entail taking into account both visual and inertial data.

Several of the above-mentioned applications will be carried on a Slow Hawk platform (figure 6).

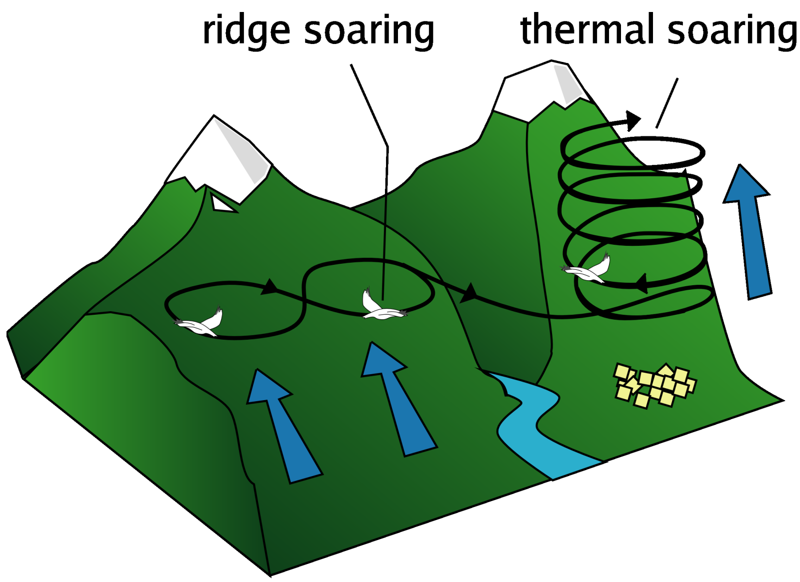

Figure 4: Depending on the relief, an aircraft can exploit different aerological features.

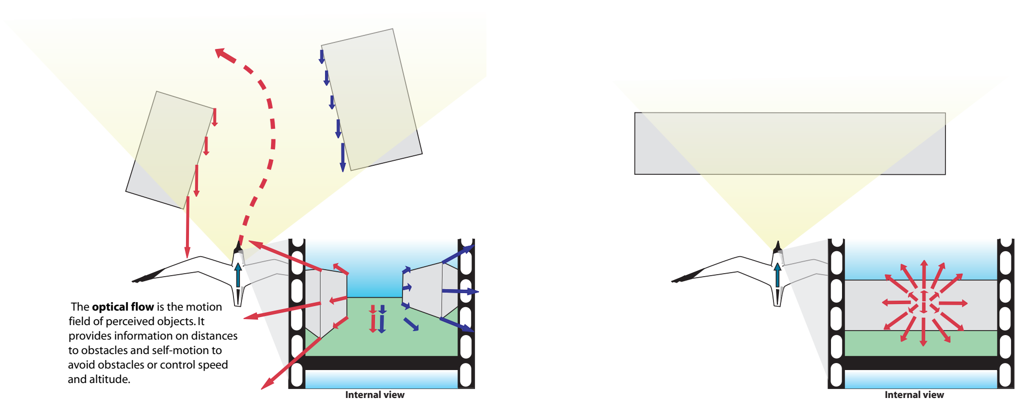

Figure 5: Left: the translational optical flow enables lateral obstacles to be avoided. Right : frontal optical flow enables frontal obstacles to be avoided.

Figure 6: The Slow Hawk is a remote controlled aircraft available off-the-shelf (http://www.ornithopter.org). It has a wingspan of 150cm. It is 75cm long and weighs 510g. It can produce 4 wing beats per second and its maximum autonomy amounts to 12 minutes. To control this platform, three different channels are available: two concern the tail - they are used to keep the pitch and the roll - and one concerns the wing beat frequency. Only the dihedral is controlled. The sweep is constant and the twist is passively controlled by the tissue of the wings. This implementation simplifies wing structure but reduces the robot's maneuverability.

This aircraft will first be used to validate the physical simulator with wind tunnel experiments[1]. Afterwards, it will be modified in order to make twist control possible thanks to a device acting on tissue tension.

3 Current state of achievement

Several research efforts that aim at fulfilling the objectives just described have already been conducted at the AnimatLab. The corresponding results are summarized below.

3.1 Motor control

When an accurate linear model of a given system is available, it is possible to design an efficient controller for this system. However, when the model is only partially known or non-linear, designing an efficient controller becomes a very difficult task.

In this context, we used alternative approaches to traditional control techniques that aim at autonomously generating such controllers, without the need of a precise or linear model. To this end, we use dedicated evolutionary algorithms to design neural networks that link an aircraft's sensors to its effectors.

This approach proved to be applicable to the control of a lenticular blimp and an helicopter [1, 2]. For instance, experiments on the lenticular blimp, for which controllers for both trim and altitude were sought, demonstrated the ability of evolutionary algorithms to autonomously exploit specific features of this platform. When it had to move up or down, evolved controllers exploited the lift that the shape of this blimp creates when it faces a frontal wind. Thus, rather

[1]Successful validations with fixed-wing aircrafts have already been done

than keeping the blimp horizontal, they slanted it up or down, thus accelerating the convergence towards the desired altitude[2]. This behavior turned out to be three times more efficient than that produced by a hand-designed controller acting on trim and altitude independently. It has been discovered autonomously, as an emergent process of evolution. No information about how variations in trim and altitude may be correlated as a consequence of physical laws was given to evolution.

Similar approaches have been applied to the control of a flapping wing aircraft. Corresponding results, as well as a more detailed description of the methodology, are described in a companion paper published in the proceedings of this conference [11].

3.2 Sensori-motor equipment

Experiments on an helicopter platform flying in a realistic 3D environment have been performed to validate the idea of exploiting optical flow to avoid obstacles.

One of the main difficulties underlying the exploitation of optical flow data, is the necessity of extracting the translational part of the flow only, because its rotational part doesn't provide information about the distances of lateral obstacles. In preliminary experiments, we committed the helicopter to follow straight trajectories with sharp turns [13]. Common flies use such a zigzag behavior to make optical flow exploitation easier. The trajectory of our UAV was then a succession of straight lines at an increasing speed, followed by a slowdown and a turn in hovering mode, and then by straight-line flight again. Being unable to compute distances to obstacles during turns, the robot had to stop before turning in order to avoid collisions during this blind phase. The corresponding behavior was efficient, as no collision occured during the different test experiments, but this strategy resulted in a slow average speed.

This constraint has been relaxed recently. Thanks to inertial information, we have been able to extract the rotational part of the flow, thus making obstacle-avoidance possible at any time, during straight flight as well as during turns [12]. This strategy, which is as efficient as the former for avoiding obstacles, allows an average speed to be reached three times faster.

During all these experiments, the maximum forward speed depended upon the perceived obstacle density (through the average motion detected in an image): the helicopter flew faster in open environments and slower in cluttered environments.

These experiments use the realistic helicopter simulator of the autopilot project[3] - controllers designed with this simulator have already been successfully used to control a real helicopter. Future work will concern flapping-wing flight and will aim at coping with the perturbations that this kind of flight might generate.

3.3 Navigation, cartography and action selection

In order to reach enough autonomy, a robot must be able to manage its energy and return to a refilling station each time it is required. Solving this problem requires several abilities.

The robot must first be able to discover and memorize places where it can refill its batteries. This issue has been tackled in our group and successfully applied to ground robots. Indeed, a former work allowed a robot to explore its environment and to incrementally build a cognitive map of it. Since the beginning of this learning process, the robot is able to self-localize on this map and to use it to plan trajectories leading to goal places[4]. Later, this system has been endowed with action selection abilities, within the framework of the Psikharpax project [6, 9, 10], thus allowing the robot to reach places where it expects to find resources - like food, water, or shelter - liable to fulfil the needs it has been endowed with - like hunger, thirst or rest. Obviously, the corresponding algorithms must be adapted to the context of flying robots. However, this will not entail starting from scratch.

[2] The lenticular shape behaves like a wing.

[3] http://autopilot.sourceforge.net/

4 Conclusion

The ROBUR project of the AnimatLab aims at designing a truly autonomous flapping-wing aircraft. Preliminary results have been obtained concerning the use of optic flow to ensure obstacle-avoidance. Similar approaches and algorithms will be used to control taking-off and landing behaviors. Likewise, preliminary results have been obtained on the evolutionary design of neural controllers ensuring forward flight. Similar approaches and algorithms will be used to make switching between hovering and forward flight possible. Finally, there are plans for extending previous results on cognitive capacities of ground robots to flying platforms that should be able to intelligently and flexibly adapt to the varying features of their environment.

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