1. Introduction

Flying insects and birds are able to navigate swiftly in unknown environments with very few computational resources. They are not guided via radio links with any ground stations and perform all the required calculations on-board. The ability to stabilize the gaze is the key to an efficient visual guidance system, as it reduces the computational burden associated with visuo-motor processing. Smooth pursuit by the eye is another requisite: the ability to fix the gaze on a given moving feature significantly reduces the neural resources required to extract relevant visual information from the environment. Although their brains are so small and their eyes have so few pixels, flying insects can perform some extraordinary behavioral feats, such as navigating in 3-D environments, avoiding stationary and moving obstacles, hovering, tracking mates and intruders, and intercepting prey, relying solely on visual guidance.

Gaze stabilization is a difficult task because the eye control system must compensate both quickly and accurately for any sudden, untoward disturbances caused by the vagaries of the supporting head or body. In the freely flying housefly, active gaze stabilization mechanisms prevent the incoming visual information from being affected by disturbances such as vibrations or body jerks [1][2]. The freely flying sandwasp, for instance, keeps its gaze amazingly stable despite the large thorax rolls it performs [3]. The stringent requirements involved in visual stabilization may explain why eye movements are among the fastest and most accurate of all the movements in the repertory of the animal kingdom.

2. The OSCAR robot

To demonstrate the efficiency of a biomimetic gaze control system once implemented onboard an aerial robot, we designed and realized a twin-engine aerial platform, called OSCAR, equipped with a self-stabilizing visual/inertial system which operates about the vertical (yaw) axis [4] [5]. In addition, OSCAR in its new version features an oculomotor mechanism that gives its eye the ability to orient relatively to its body within a range of 35°. This additional degree of freedom mimicks the mechanical decoupling between eye and body that is so characteristic of animals, from box jellyfish to humans. The sighted robot is able to adjust its heading accurately about the body yaw axis by driving its two propellers differentially via a miniature custom made 1-g dual sensorless speed controller (for a detailed description, see [6]). The robot's "body" consists of a carbon housing containing the two motors driving the robot's propellers' (see figure 1).
OSCAR-II is a tethered aerial robot which controls its heading about the vertical (yaw) axis by driving its two propellers differentially, based on what it sees. The eye of OSCAR-II is **mechanically decoupled** from the head (which is mounted firmly on the "body"). The visual system enables the robot to fixate a target (a vertical edge placed 1 meter ahead). Two oculomotor reflexes (ORs), the vestibulo-ocular reflex and the visual fixation reflex, stabilize the robot's line of sight (its gaze) in response to any severe disturbances (such as gusts of wind) liable to affect its body. The heading control system in which the ORs are involved aligns the robot's heading with the gaze, and is thus constantly catching up with the gaze. Adapted from [5]

Like its predecessor OSCAR-I [4], OSCAR-II (see figure 1) is a twin-engine aerial platform equipped with a self-stabilizing visual/inertial system which operates about the vertical (yaw) axis. The OSCAR-II robot weighs 65g without the batteries. This weight includes the two engines with their drive mechanisms and their dedicated sensorless controller [6], the propellers, the eye with its voice-coil motor (VCM) based position servo-system, the micro rate gyro (Analog Device ADIS 16100), the piezo bender, the complete electronics based on Surface Mounted Device (SMD) technology and the blue-tooth circuit for remote data monitoring.

The robot's "head" is a large (diameter 15mm) carbon tube mounted firmly onto the motor casing. Within the head, an inner carbon "eye tube" can turn freely about the yaw axis. This eye tube is spring-loaded between a pivot bearing (at the bottom) and a bored micro-conical ball bearing (at the top), through which a 1-mm steel axle passes freely. Thanks to a micromagnet glued to the tip of this axle, a tiny contactless Hall sensor accurately gauges the eye-in-robot orientation. The complete visual system including the complete OSCAR sensor (see [7]), its VCM, its driver and the digital controller weighs only 22.5g.

### 3. Experimental results

To further assess the robustness of the OSCAR-II robot in terms of its ability to reject aerodynamic perturbations, the robot was presented with a vertical edge that was made to translate sinusoidally in a frontal plane 1m ahead, and the robot’s visuo-motor behaviour was tested in the presence of strong gusts of wind. The target’s translation was accurately controlled (resolution of 0.125mm) by a stepper motor driven in the microstep mode by a dSPACE board. The translation sequence was a slow sinusoid (period of 36s) of a large...
amplitude (78cm peak-to-peak, causing an angular excursion of 42° with respect to the robot’s eye). A series of brisk random aerodynamic perturbations was applied here (see figure 2).

Figure 2. Visual tracking behavior of the OSCAR-II robot with its ORs activated during the visual pursuit of the translating target. The robot's heading (red continuous line in figure 2a) can be seen to have followed the target throughout the whole cycle; compensating smoothly and accurately for the strong random gusts of wind applied to one of its propellers (from 0s to 40s, figure 2b) and never loosing sight of the moving target. This attests that when the ORs are activated the robot manages to reject the strong aerodynamic perturbations robustly throughout the cycle with its gaze locked onto the moving target. Adapted from [5]

4. Future work

The lightness and low power consumption of the gaze control system would make it particularly suitable for application to MAVs and underwater vehicles which are prone to disturbances due to untoward pitch and roll variations, wing-beats (or body undulations or fin-beats), wind gusts (or water streams), ground effects, vortices, and unpredictable aerodynamic (or hydrodynamic) disturbances of many other kinds. Lessons learned from biological creatures teach us that it is best to compensate early on for these disturbances, which was done here by using a visuo-inertial gaze stabilization system as the basis for efficient heading stabilization. Anchoring the gaze on a contrasting feature in the environment provides a robust, drift-free starting-point for implementing a visual-based hovering with a high accuracy.

5. References


