Insects as pilots: optic flow regulation for vertical and horizontal guidance

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When insects are flying forward, the image of the ground sweeps backward across their ventral viewfield and forms an 'optic flow' (OF) that depends on both the groundspeed and the groundheight. Ever since Kennedy has put forward the hypothesis that insects have a 'preferred' retinal velocity with respect to the ground below [1], several studies have shown that insects are able to maintain a constant OF with regard to their surroundings while cruising and landing, without having to measure their groundspeed and groundheight. Our recent research attempted to establish an explicit flight control scheme that can allow insects to behave in this way [2].

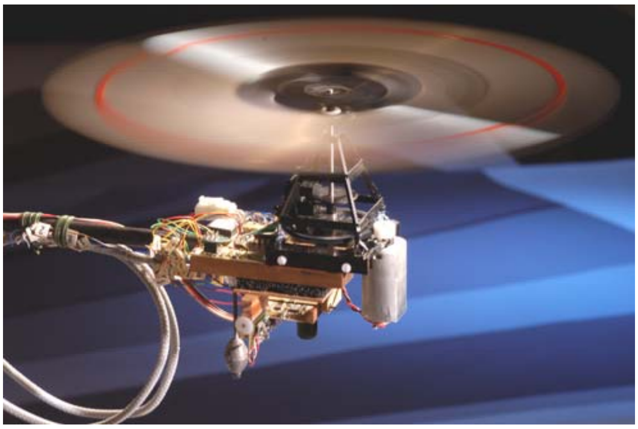

Fig. 1. The robot OCTAVE equipped with a ventral OF sensor and an *OF regulator* mimics insect behaviour in the vertical plane

We put forward the concept of *optic flow regulator* that may account for both insects' ground avoidance and lateral obstacle avoidance, while offering interesting solutions to MAV's automatic guidance systems based on vision [3,4]. The word 'regulator' is used here in the strict sense to describe a feedback control system that strives to maintain a variable at a fixed set-point. The variable measured is, however, neither the groundspeed nor the distance but the groundspeed:distance ratio - in other words the *optic flow* - which the insect can access directly via motion detecting neurons. In the vertical plane, the insect will alter its vertical lift, and thus its groundheight, to maintain a set-point of ventral OF at all times. Once reaching a given groundspeed, the insect is bound to maintain a constant height above varying terrain and therefore to 'follow' the terrain. If the insect increases its forward speed, it will automatically increase its groundheight. If its groundspeed decreases for whatever reason - whether the insect plans to land or faces a headwind - the *OF regulator* will force it to descend to hold again the groundspeed: groundheight ratio at the OF set-point. Strong headwind will lead to forced - but smooth - landing. The *OF regulator* concept accounts for a number of seemingly disparate insect behaviours that were reported over the last decades. Most reports are qualitative, but recent quantitative findings made on honeybees' landing [5] can also be explained on the basis of this simple control system, including the constant descent angle observed in the bee's final approach [6].

In a similar vein, a honeybee trained to fly in a corridor [5] may rely on a *dual OF regulator* to adjust both its forward speed and its clearance to the walls, by controlling its forward and side thrusts, respectively, without ever measuring its forward speed and distance to the walls [7,8].
Our thinking along these lines was aided not only by simulation experiments but also by physical implementation of *OF regulators* onboard two kinds of MAVs: a robotic helicopter for ground avoidance (Fig.1) and a robotic hovercraft for lateral obstacle avoidance and speed control. In both cases, the electronic OF sensor [9,10] was derived from the housefly Elementary Motion Detector (EMD), which we had previously analysed using single neuron recording combined with optical microstimulation of two photoreceptor cells within a single ommatidium [11].
The block diagram of the *optic flow regulator* describes not only the *causal* but also the *dynamical* relationships between measured and controlled variables, while pinpointing the specific loci of the various disturbances that may affect the control system behaviour.

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