

Neuromorphic motion detection for robotic flight guidance

Flying insects use the relative motion of contrasts, or Optical Flow (OF), to detect and avoid obstacles. A fly's compound eye converts changing light intensities into visual motion information in 5 stages (fig. 1): 1/ Optical smoothing by lenslets; 2/ Light intensity conversion into neural signals by photoreceptors in ommatidia; 3/ Signal amplification via neural convergence in the lamina; 4/ Motion detection by elementary motion detector (EMD) neurons in the medulla; 5/ Motion signal aggregation by directional neurons in the lobula plate. The reduced visual information contributes to the generation of flight commands. This article describes how an insect's visual processing chain was replicated to control a flying robot's altitude¹.

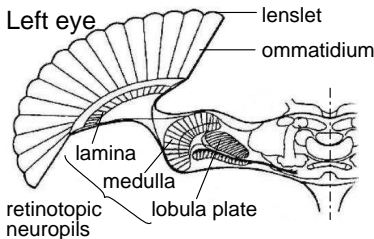


Figure 1. The blowfly's visual system²

Light intensity sensing

A fly has 700 to 3000 ommatidia per compound eye. Each ommatidium is capped by a lenslet which projects about 1 deg of the visual field onto its 8 photoreceptors. The projected image is slightly blurred locally. Therefore, the image is smoothed over the compound eye with benefits for motion detection because more photoreceptors can witness a contrast's motion for more time. It also prevents aliasing artefacts due to spatial discretization by the compound eye. Signals of complementary photoreceptors from hexagonally adjacent ommatidia are then amplified via neural superposition in the lamina neuropil.

For a robot, one can design a simpler camera eye which is equivalent to a compound eye for OF analysis (fig. 2). The flying robot's camera eye contains a one-dimensional, 20-pixel linear photoreceptor array and an aspheric lens (focal length 24 mm) set at only 13 mm from the array. Defocus is adjusted so that the Angular Sensitivity Function's width at half height, the acceptance angle, is slightly greater than the interreceptor angle. The eye is tilted (-50 deg) so that its field of view (FOV = 75 deg) covers the frontal and ventral region. Electrical signals from the photoreceptors are then fed to op-amps.

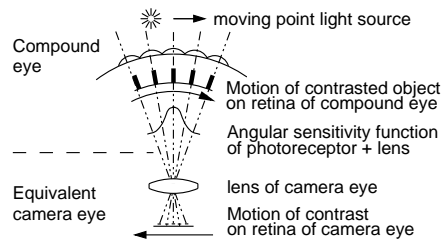


Figure 2. The equivalent camera eye

Motion detection

The velocity of contrasts is computed by EMD neurons ordered retinotopically in the medulla. As a feature moves across the FOV of two adjacent ommatidia, an EMD correlates the delayed output of the lamina's first neurally superposed photoreceptive column with the output of the second column.

The aircraft's photoreceptor array connects to 19 electronic EMDs (fig. 3a). As with insects, each EMD detects motion in a particular direction within the visual field seen by 2 adjacent photoreceptors. The first channel filters the photoreceptor signal into a pulse with decaying exponential and the second into a spike. Multiplication of both channels outputs a pulse whose voltage is nearly inversely proportional to the time delay between both photoreceptor excitations – hence quasi-proportional to speed. Outputs are digitized by a PC.

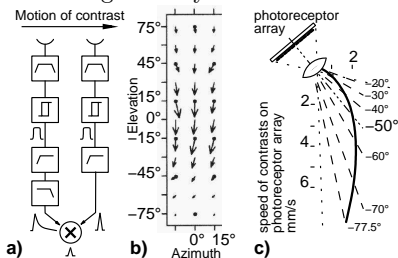


Figure 3. EMD, vertical system neuron response², and retina motion distribution

Motion signal aggregation

Of the 60 tangential neurons of the lobula plate, 10 Vertical System neurons aggregate motion information along azimuthal planes. Neurophysiological data shows that the frontal vertical neurons are most responsive to downward stimuli directly ahead of the fly² (fig. 3b).

The robot's flight computer digitally aggregates frontal to ventral motion by using a weighted average rule that gives more weight to motion in the frontal FOV than in the ventral FOV. The rule normalizes the OF distribution that corresponds to a reference flight condition at a predefined altitude and flight speed over horizontal ground (fig. 3c).

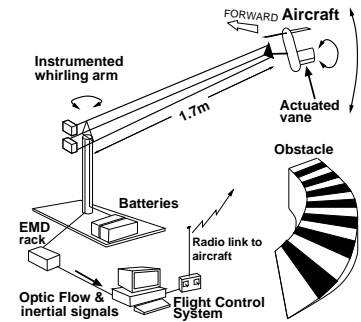


Figure 4. Rotorcraft on whirling arm

Flight guidance

Altitude control using OF was demonstrated on a tethered rotorcraft (34 cm) using the rotor's collective pitch to vary thrust and a blown aerodynamic vane to regulate pitch (fig. 4). The flight control system (FCS) commands thrust to vary height above ground in order to control in-flight OF with respect to the reference OF setpoint. If OF is below setpoint then the aircraft is too high and thrust is decreased, and vice versa. The paradigm supposes a constant flight speed that is regulated using an onboard pitch inclinometer. Although neuromorphic motion detection uses discrete analog electronic components, the FCS uses a 20 Hz Real-Time Linux loop.

Similarly to flying insects, the aircraft uses visual motion to control its altitude. Landings were simulated by voluntarily decreasing flight speed while retaining the reference OF. The aircraft flew at nearly 3 m/s and 30 cm above a 30 deg ramp climbing up to 1.5 m. The smoothed vision system and its weighted average FCS generate smooth trajectories. An advantage of the system is that an increase in flight speed induces an increase in altitude, thereby increasing the level of safety with respect to obstacles. The strategy also works in free flight³.

Thomas Netter and Nicolas Franceschini
tnetter@ini.unizh.ch

franceschini@laps.univ-mrs.fr
CNRS Biorobotics, 31 Ch. J. Aiguier,
13204 Marseille Cedex 20, France

References

1. T.Netter and N.Franceschini, *A Robotic Aircraft that Follows Terrain Using a Neuromorphic Eye*, Proc. IEEE/RSJ IROS'02, pp.129-134, 2002.
2. H. G. Krapp, B. Hengstenberg and R. Hengstenberg, *Dendritic structure and receptive-field organization of optic flow processing interneurons in the fly*, J. Neurophys. (79), pp 1902-1917, 1998.
3. G. L. Barrows, J. S. Chahl, and M. V. Srinivasan, *Biomimetic visual sensing and flight control*, Proc. Bristol UAV Conf., 2002.