Bee-inspired vision-based robots

Franck RUFFIER

CNRS Research Scientist, *Co-Head of the Biorobotics Lab.*

Institute of Movement Sciences, UMR ISM

CNRS / Aix-Marseille University, France

franck.ruffier@univ-amu.fr *www.ism.univ-amu.fr/ruffier*

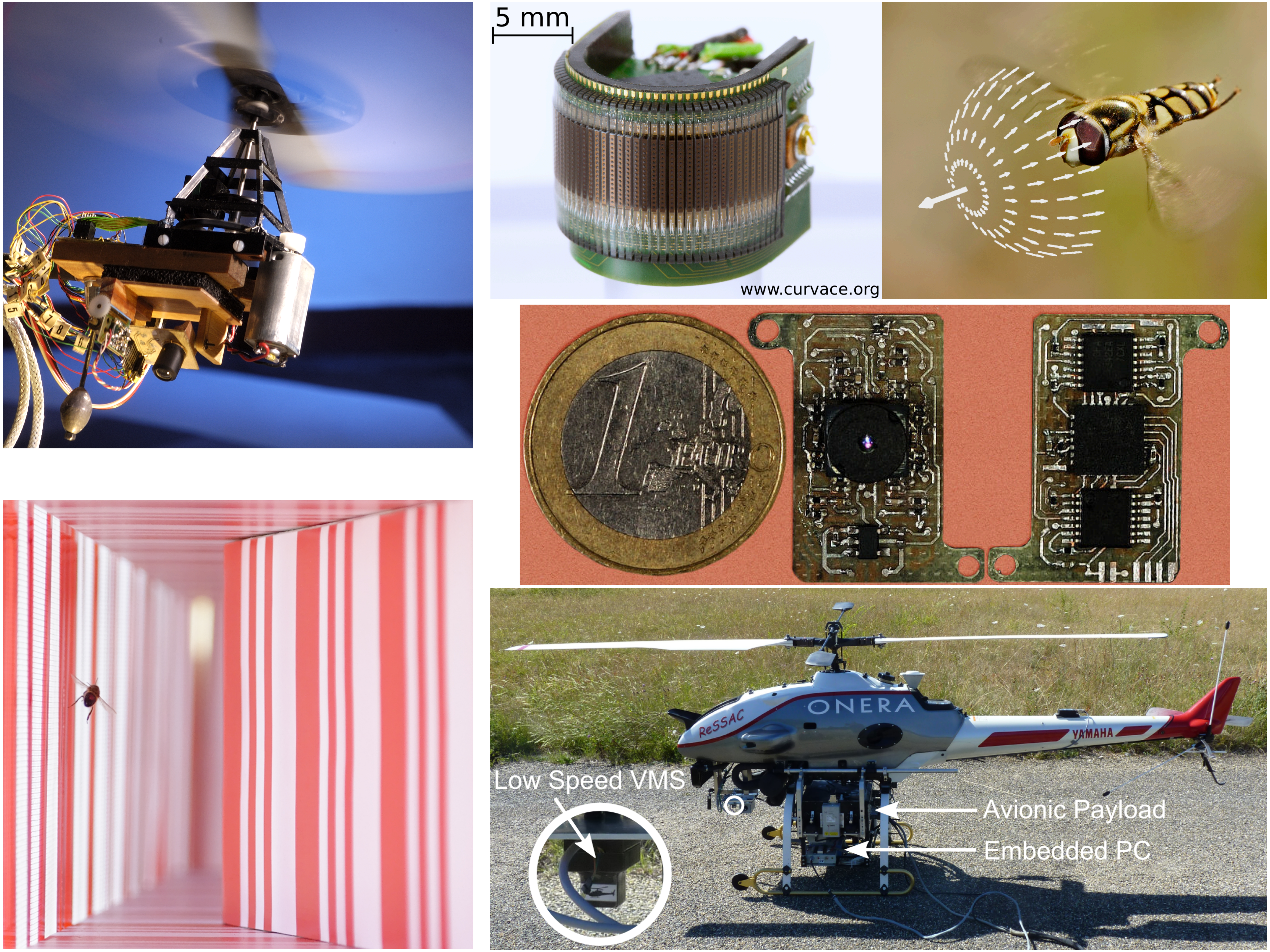
The Biorobotics scientific method

Motion detection
Target tracking
Sensori-motor control

Inspiration

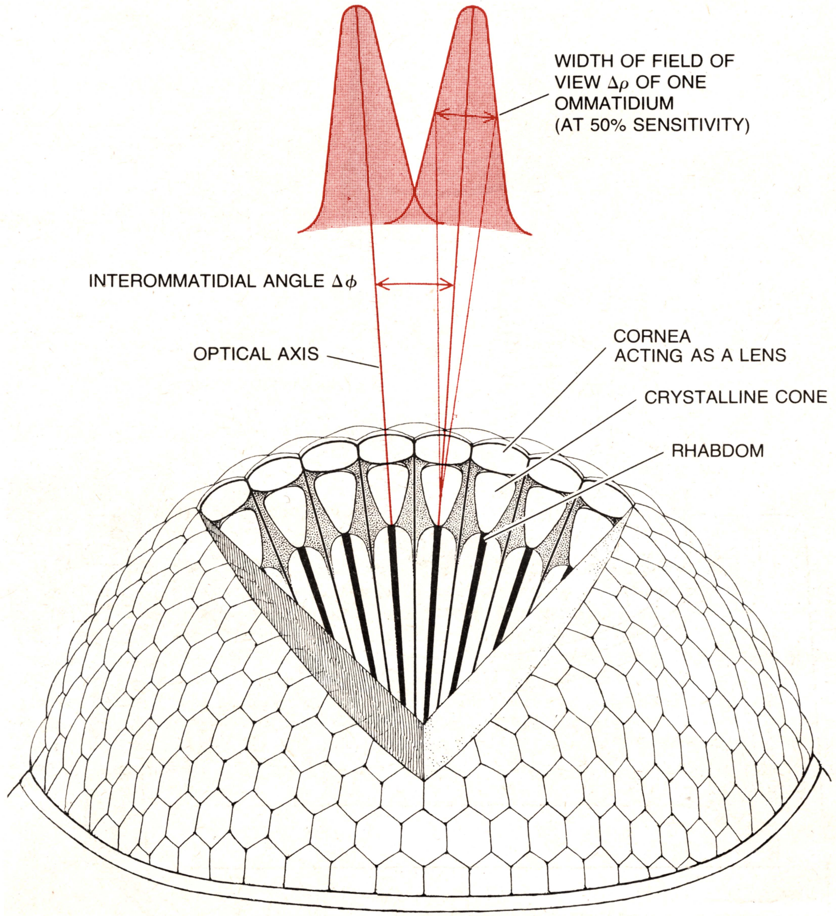
Fly
Hovefly
Wasp
Bee

Autonomous robots
Visual sensors
Navigation strategies


5 mm
www.curvace.org
ONERA
ReSSAC
YAMAHA
Low Speed VMS
Avionic Payload
Embedded PC

Insect compound eyes

Franceschini – J. Physiol. Paris - 2004



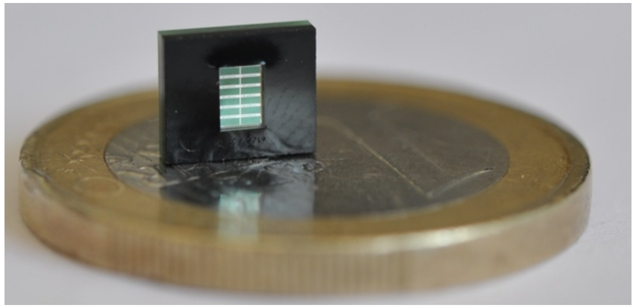
Horridge - 1977

Optic flow

Winged insects used the optic flow to navigate : $\omega \sim \frac{V}{D} \sin \Phi$

Lens/photodiode assembly

Linear array of 6 photodiodes

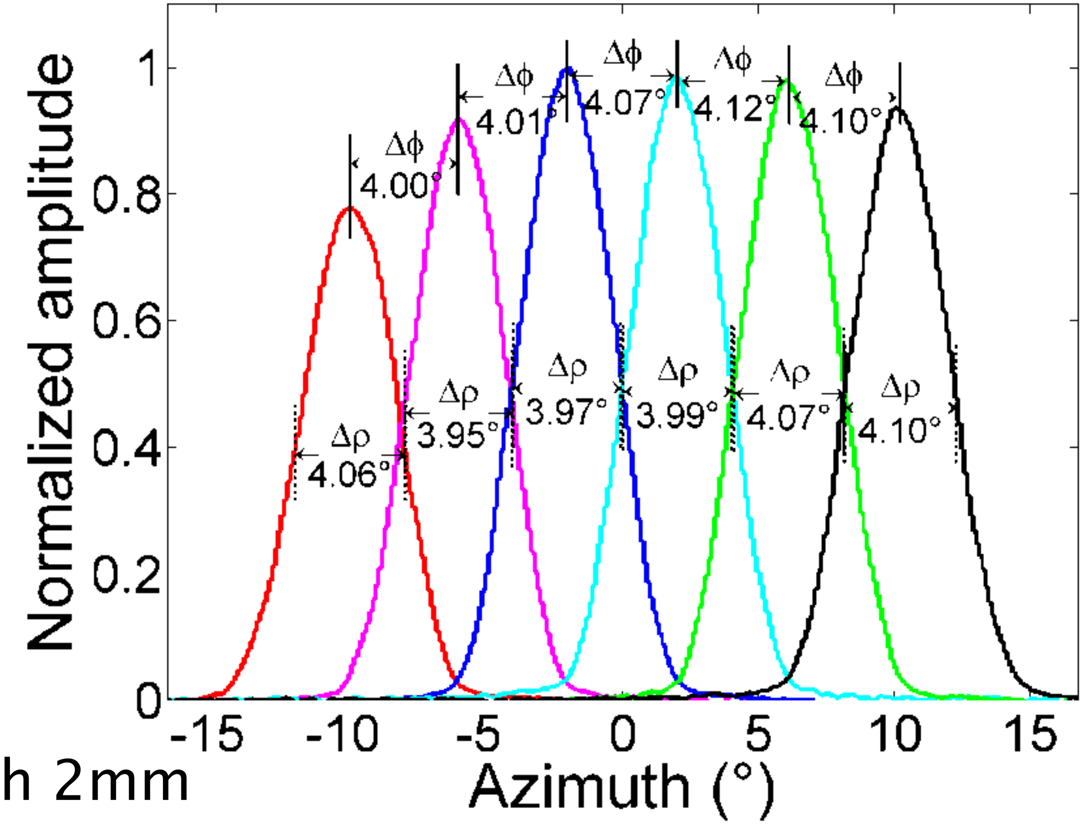


- Linear on-chip current preamplification circuit

Lens from Sparkfun™

- Focal length 2mm
- f-number 2.8

Gaussian angular sensitivities

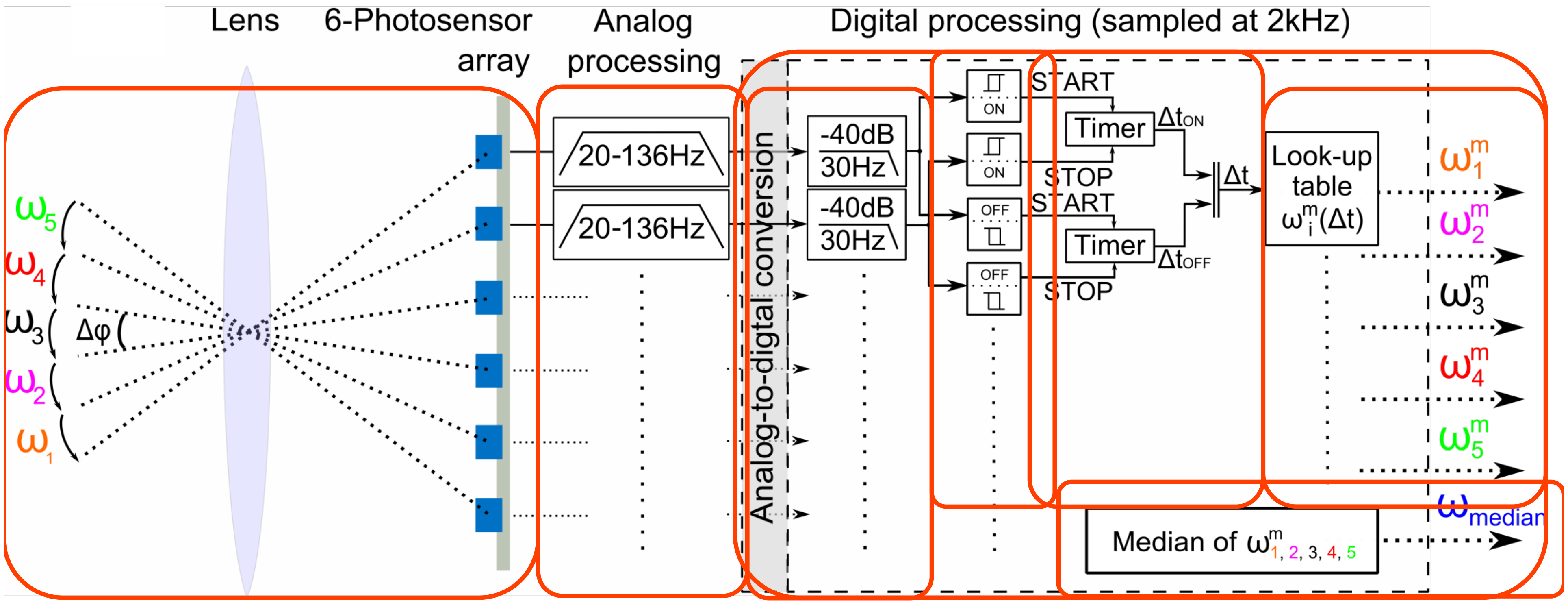


F. Roubieu *et al., IEEE Sensors Journal, 2013*

Optic flow processing

Time of travel scheme : 6 processing steps

$$\omega_i^m = \frac{\Delta\varphi}{\Delta t_i}$$



Implemented into a tiny 16bits dsPic microcontroller !!

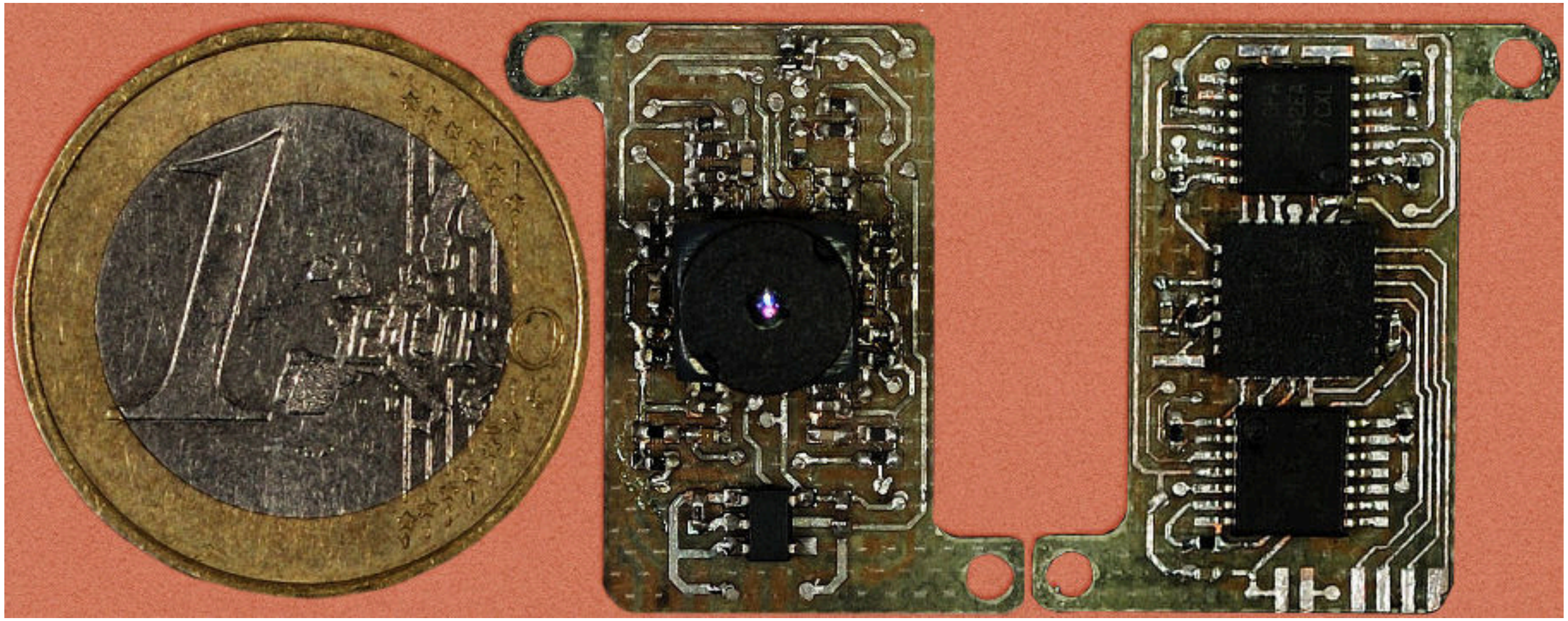
F. Roubieu *et al., IEEE Sensors Conf., 2011.*

Design of a tiny visual motion sensor

-> 5 single 1-D angular speed measurements, $\omega \in [25°/s; 350°/s]$

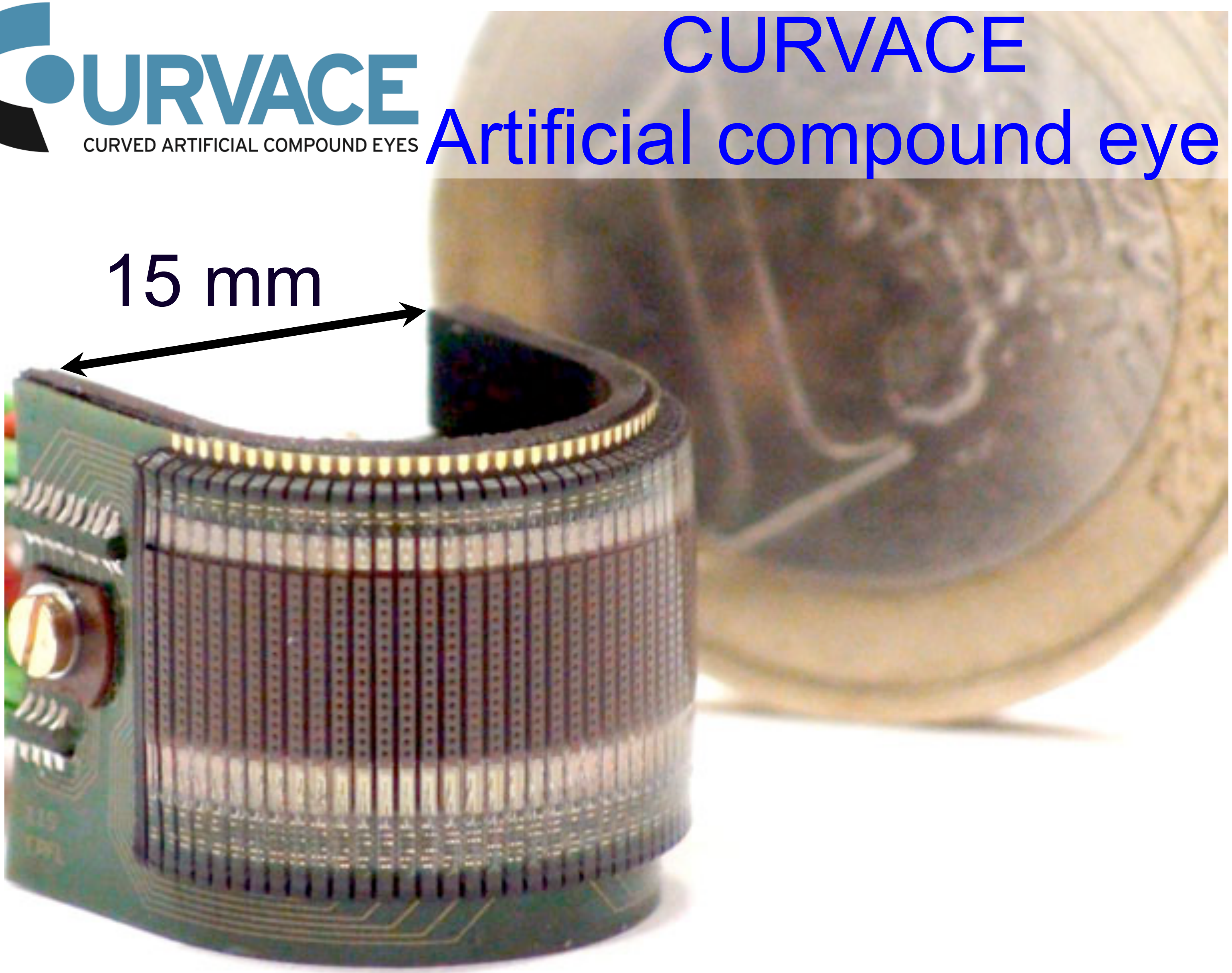
-> 1 fused output : median of the 5 single measurements

-> Size, mass and power-consumption reduced



F. Roubieu *et al., IEEE Sensors Journal, 2013*

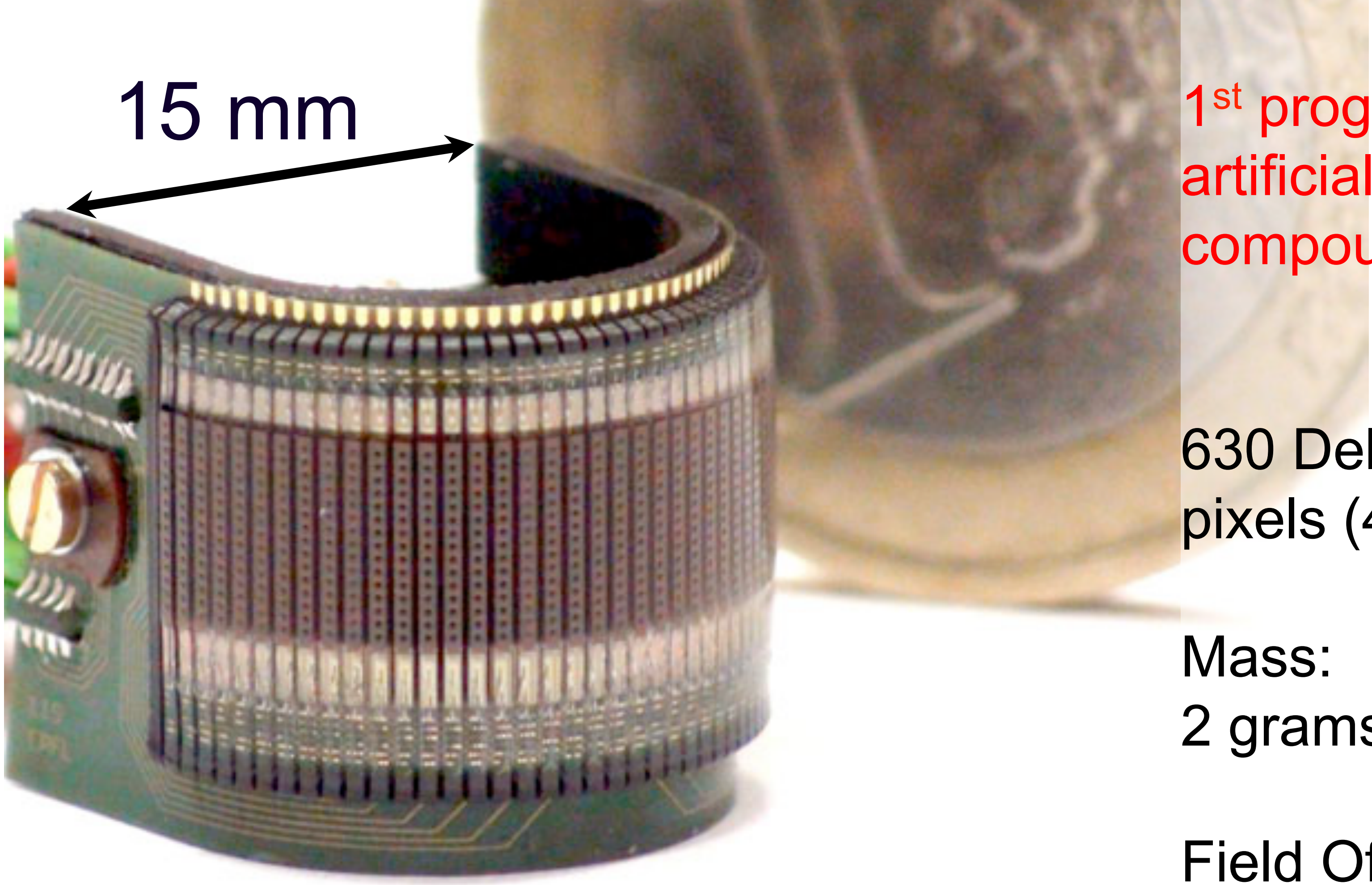
CURVACE
Artificial compound eye



Floreano *et al.* (2013) *PNAS*

CURVACE (ICT/FET) European project www.curvace.org

CURVACE
Artificial compound eye



Floreano *et al. (2013) PNAS*

1st programmable artificial compound eye

630 Delbrück pixels (42x15)

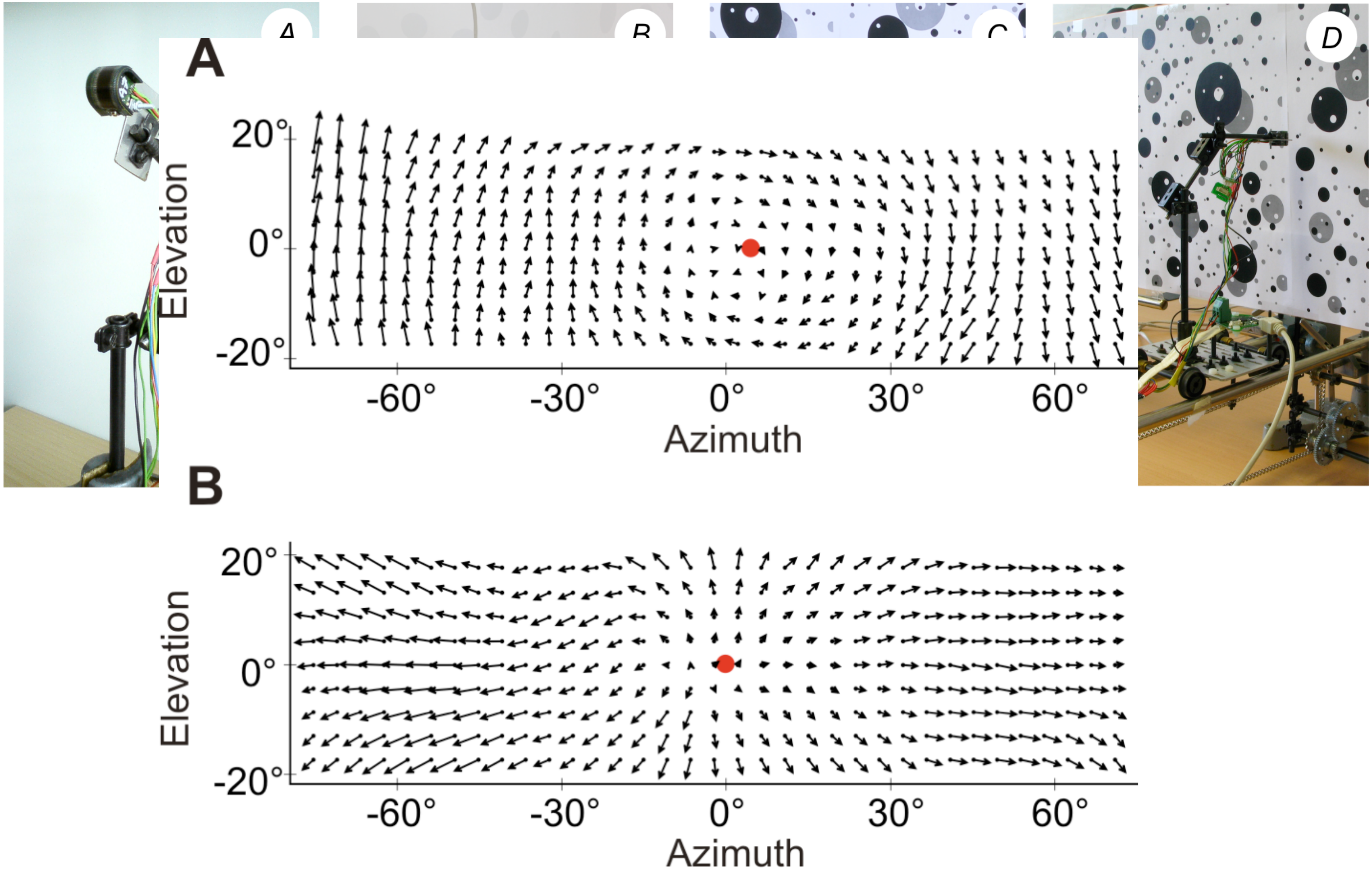
Mass:
2 grams

Field Of View:
180° x 60°

CURVACE (ICT/FET) European project

www.curvace.org

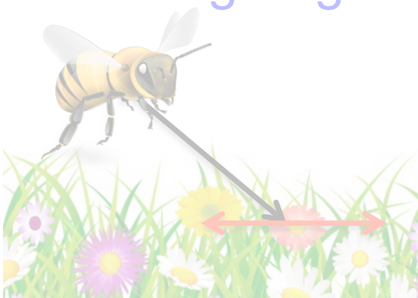
Optic flow measurement

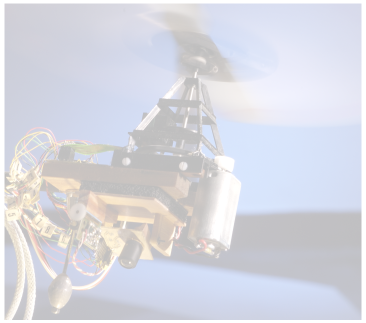


Floreano, Pericet, Viollet, Ruffier et al., *PNAS*, 2013

3 proof-of-concept robots based on optic flow
=> accounting for flying insect behaviors

Flying with the wind and Landing on a moving target

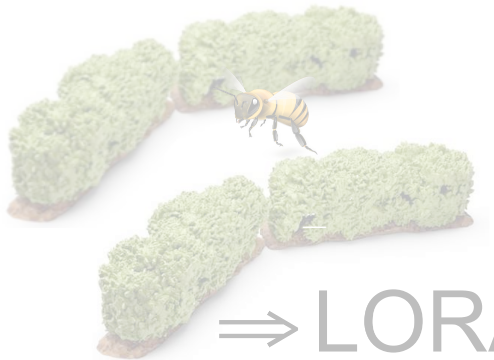




Ruffier, Franceschini (2005, 2014)

⟹ OCTAVE

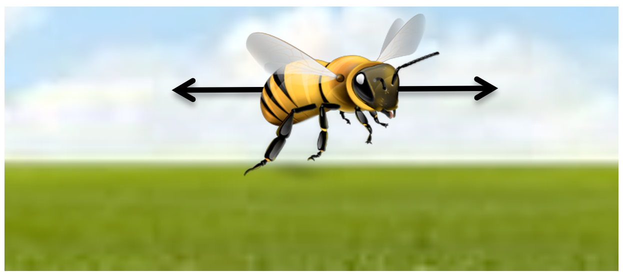
Position and speed control in narrow corridor

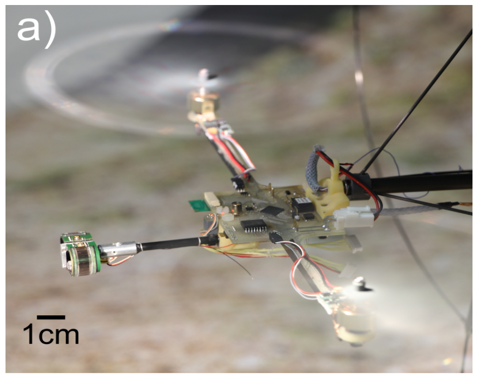


Roubieu et al. (2014) Bioinsp. Biomim.

⟹ LORA

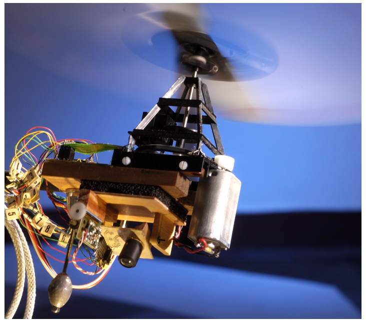
Stabilize pitch without IMU nor accelerometer





Expert, Ruffier (2015) ⟹ Beerotor

Flying with the wind and Landing on a moving target

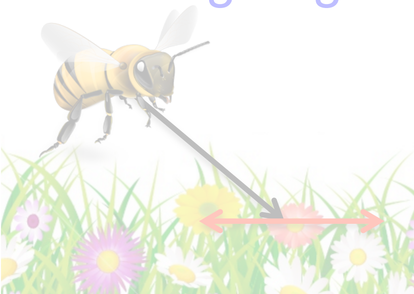


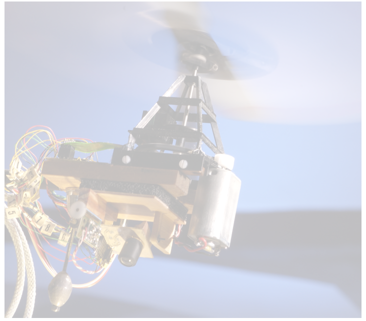
Ruffier, Franceschini (2005, 2014)

$\Longrightarrow$ OCTAVE

3 proof-of-concept robots based on optic flow
=> accounting for flying insect behaviors

Flying with the wind and Landing on a moving target

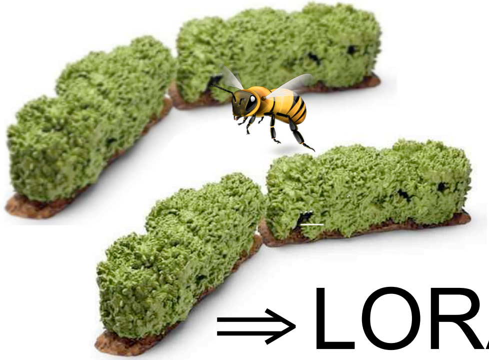




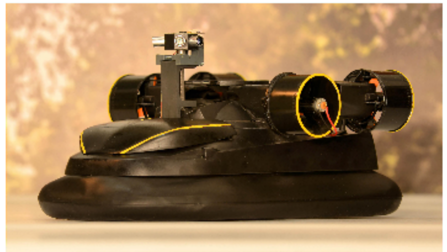
Ruffier, Franceschini (2005, 2014)

⇒ OCTAVE

Position and speed control in narrow corridor

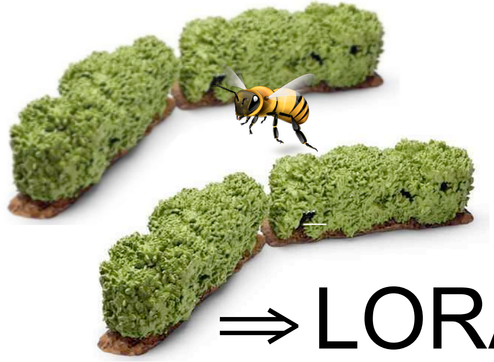


⇒ LORA

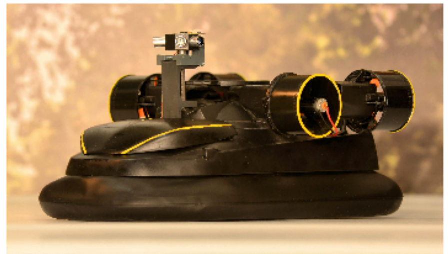


Roubieu et al. (2014) Bioinsp. Biomim.

Position and speed
control in narrow corridor

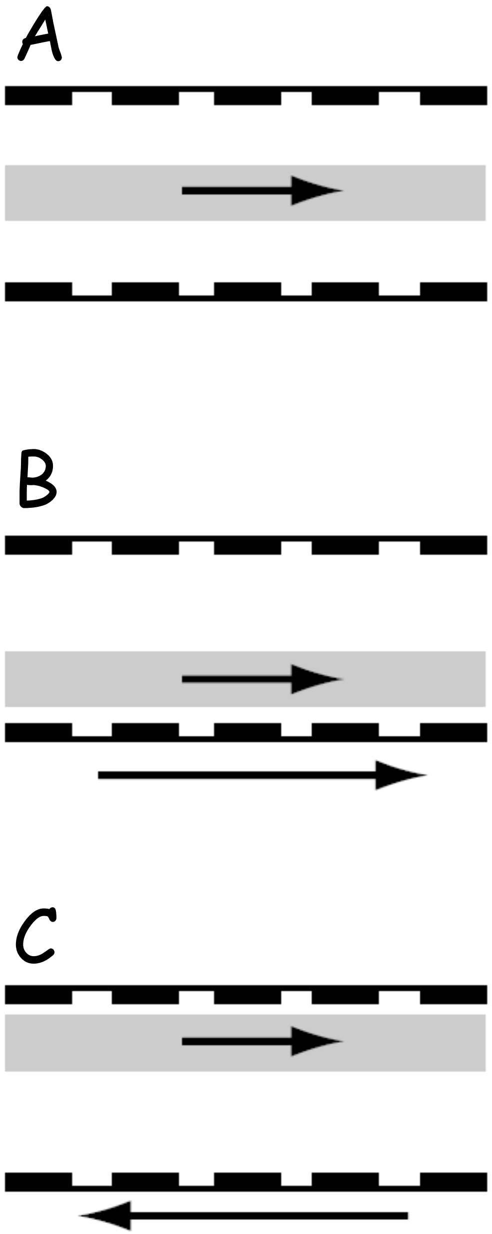


⇒ LORA



Roubieu et al. (2014)
Bioinsp. Biomim.

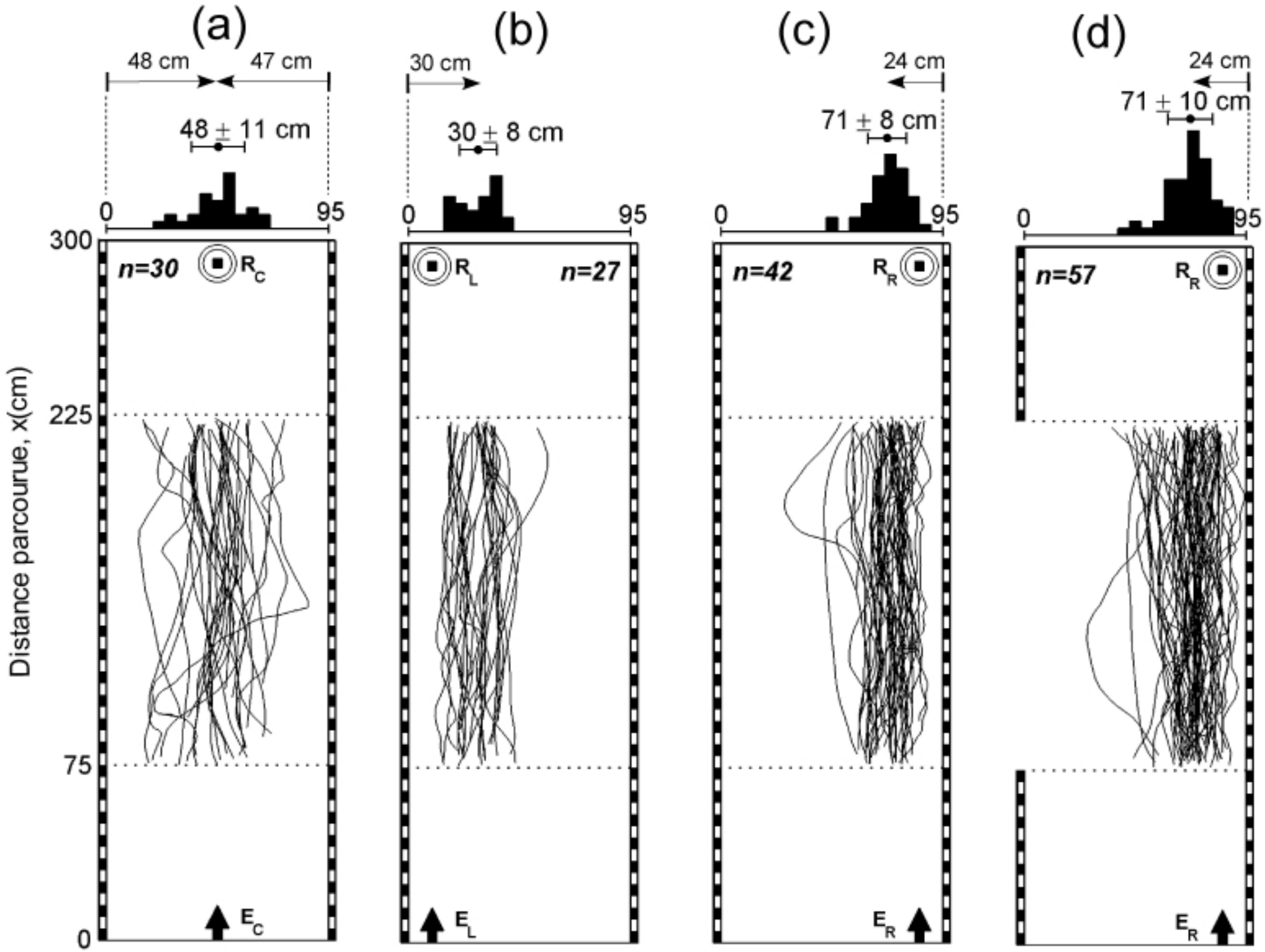
Source of inspiration: Srinivasan et al. 1989,1991,1996



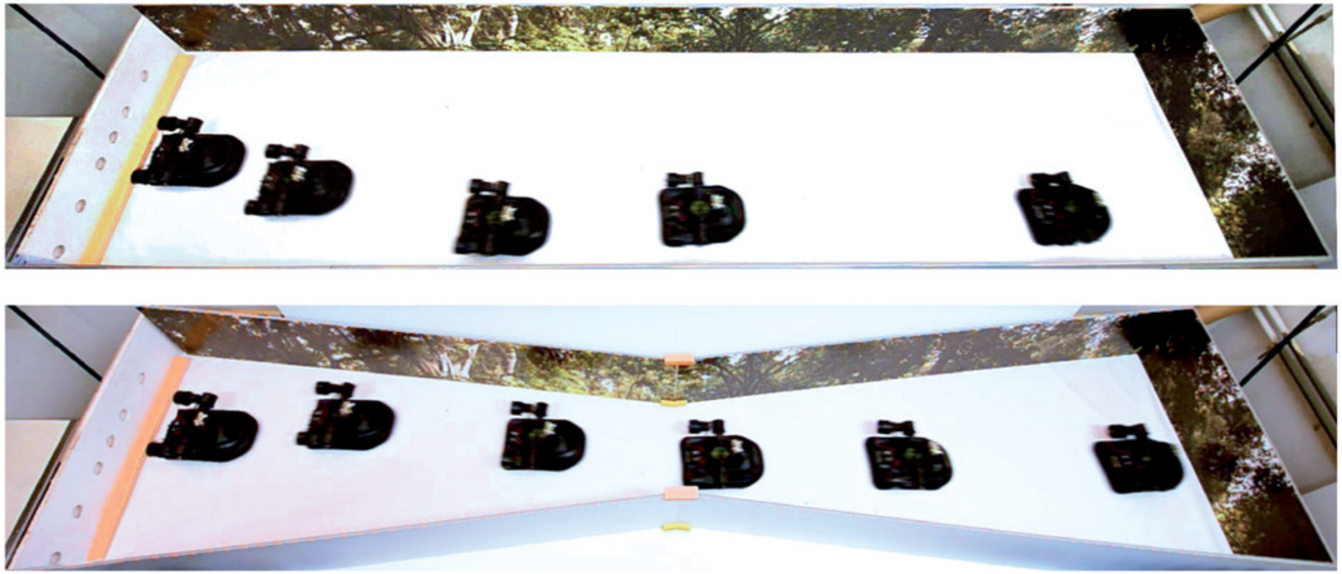
- Bees normally show “centering behavior”

- Bees do not react to the distance from the walls but to the Optic Flow (OF)

Honeybees in a much larger corridor

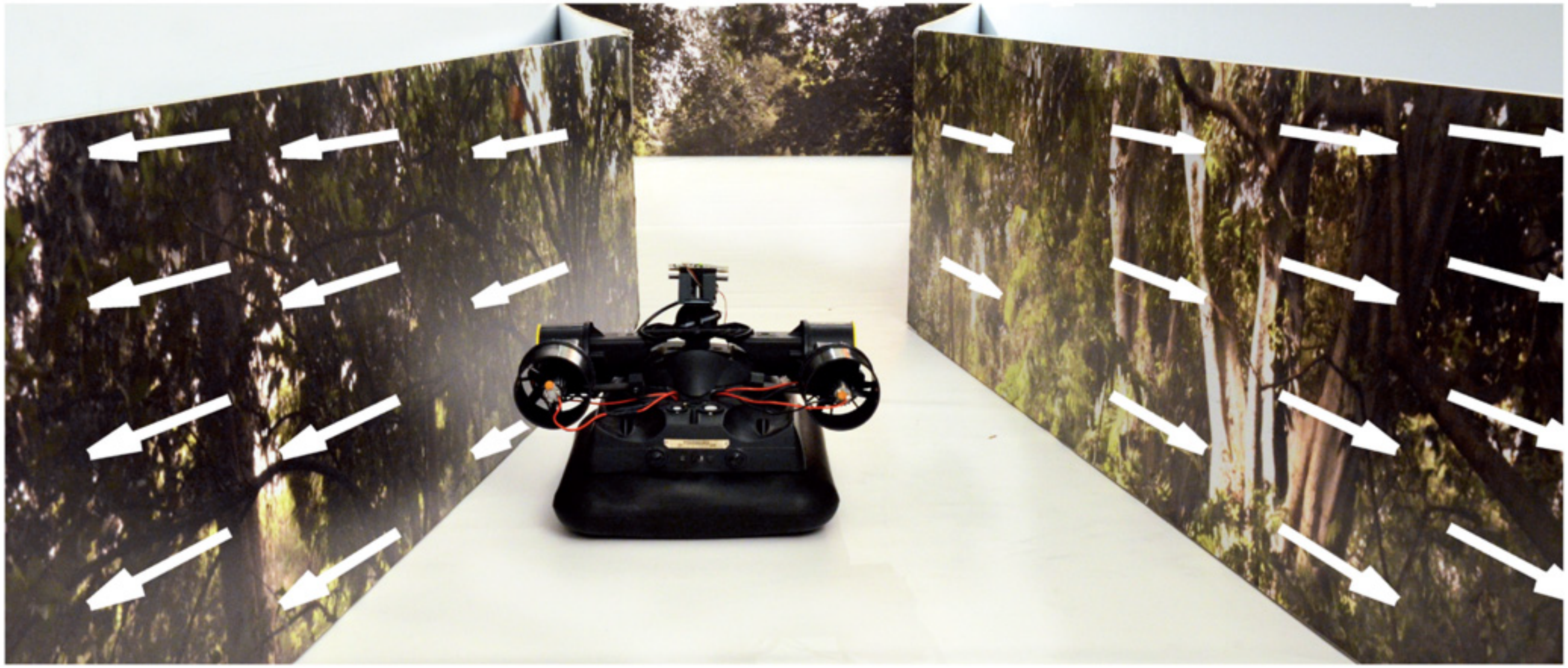


Serres et al. (2008) Naturwissenschaften, vol. 95(12), pp. 1181-1187

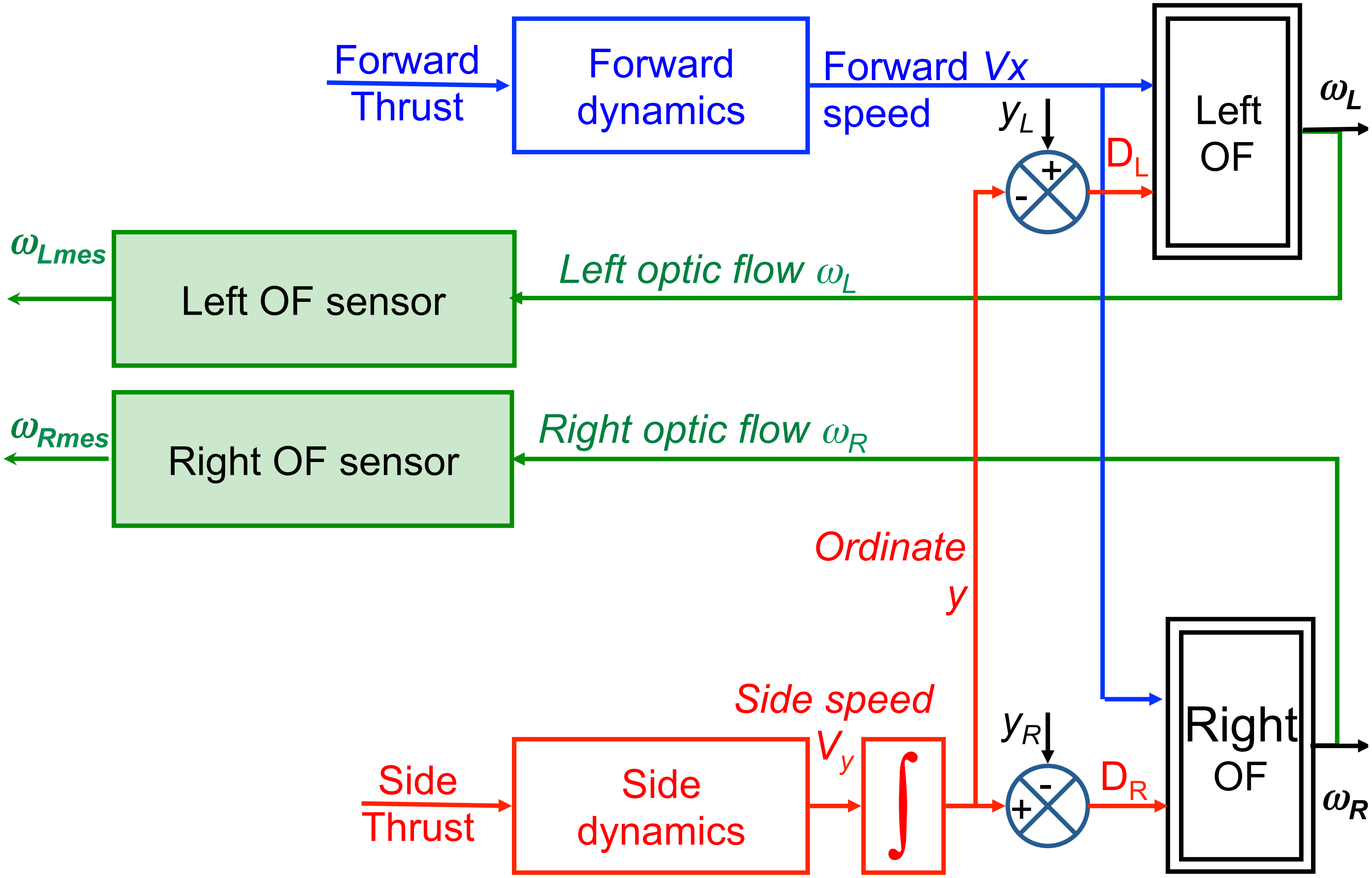


The robot LORA

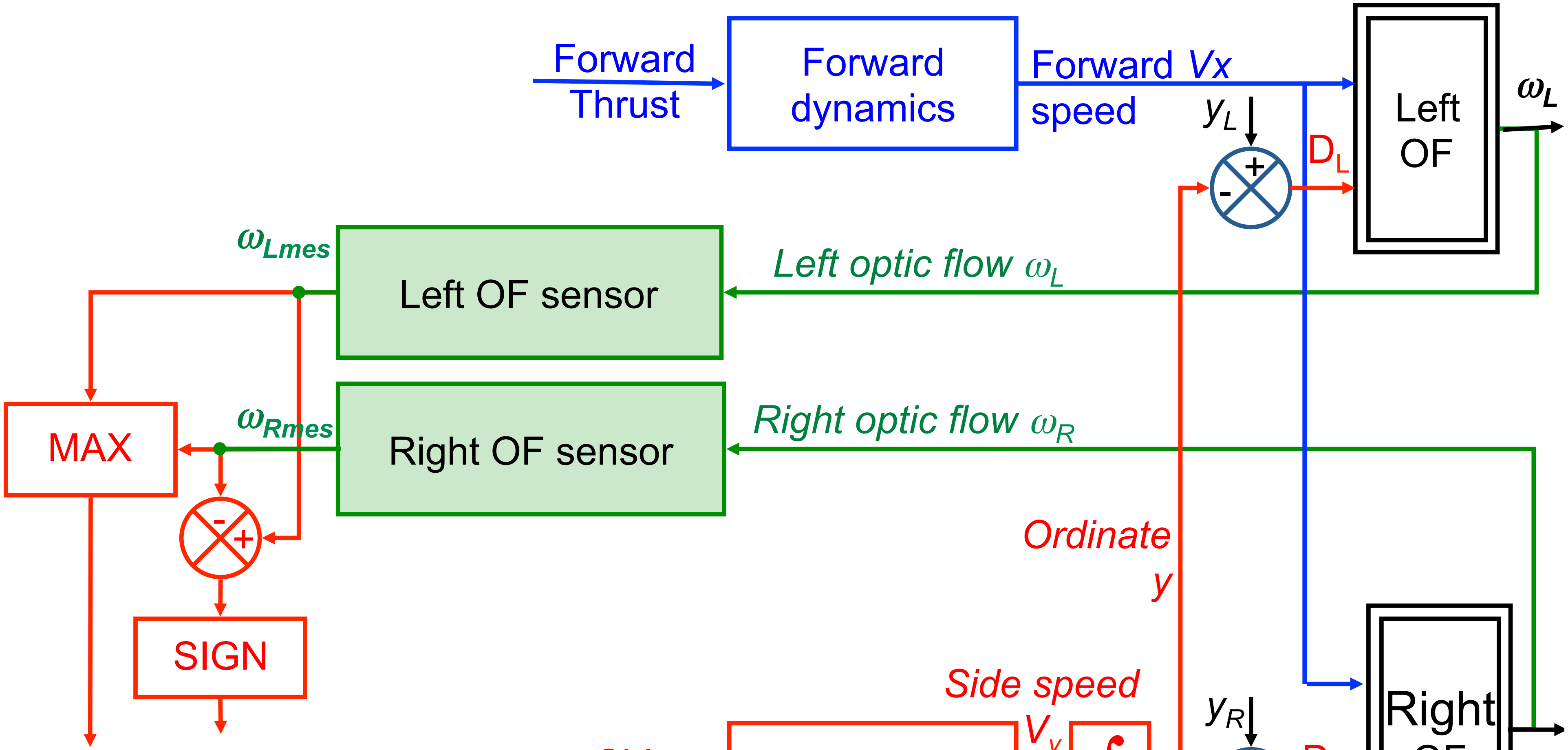
Roubieu et al. (2014)
Bioinspir. Biomim.



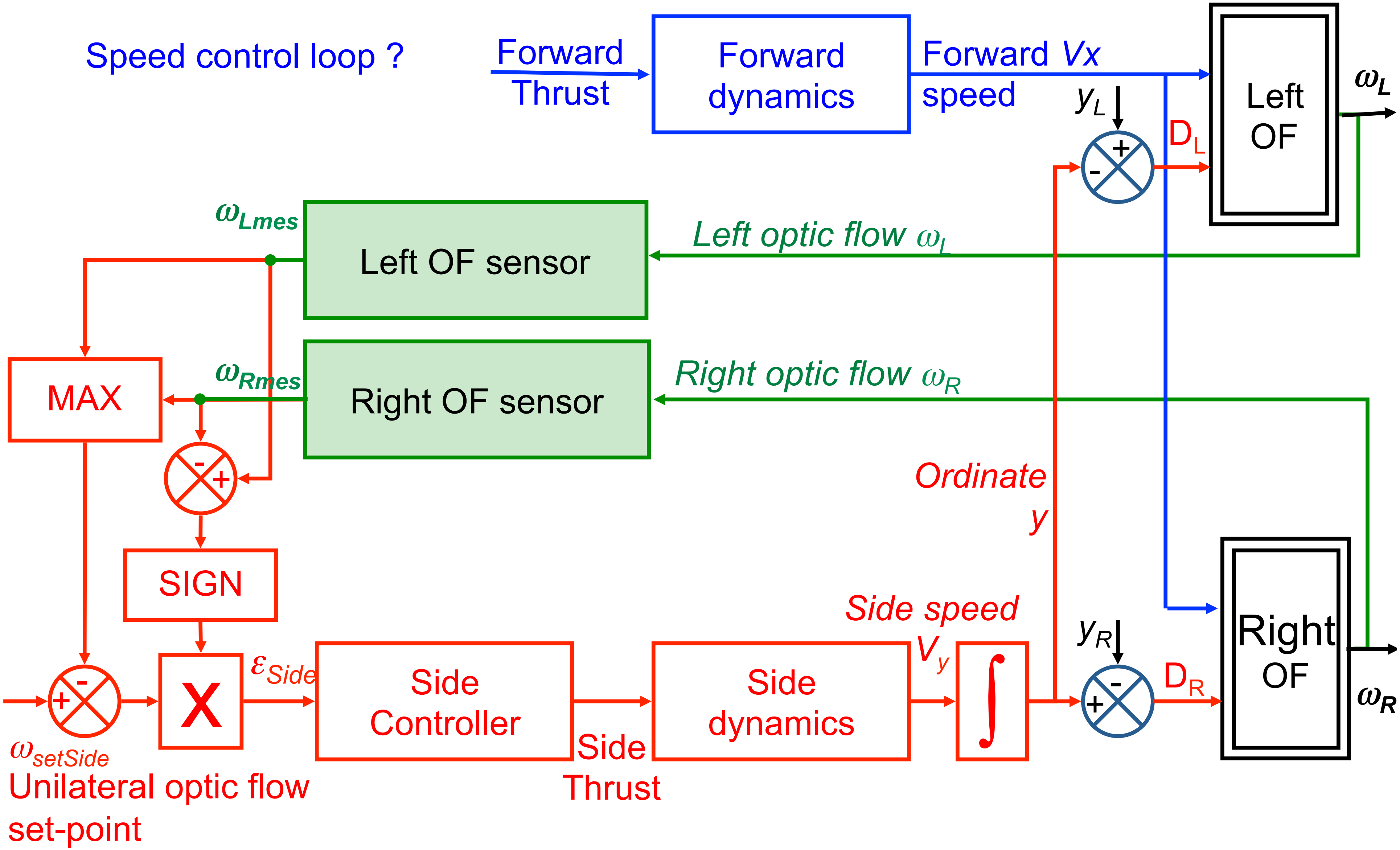
Optic flow (OF) measurement



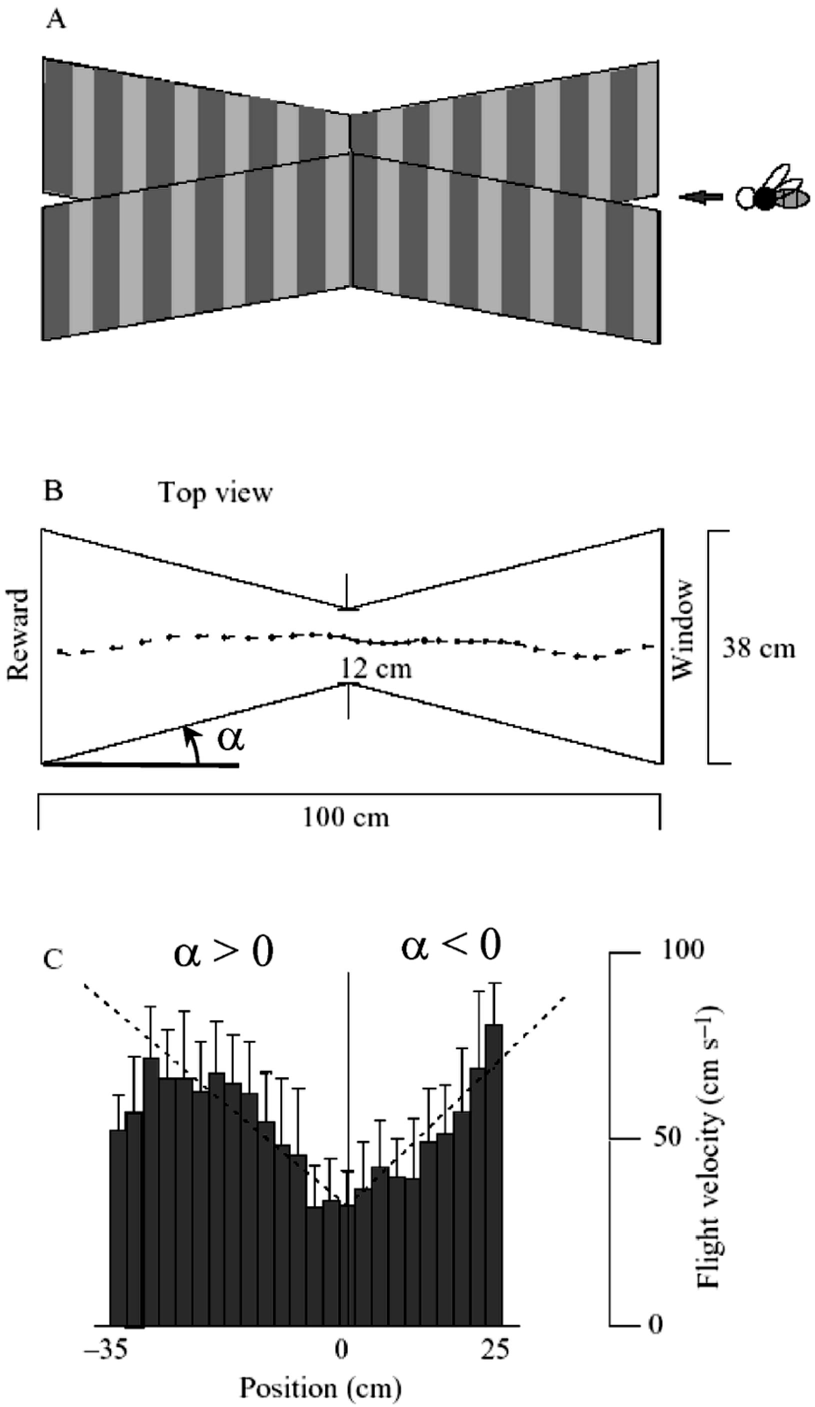
Selection of the wall to follow



The side control loop



Speed control loop: Source of inspiration



Observation:

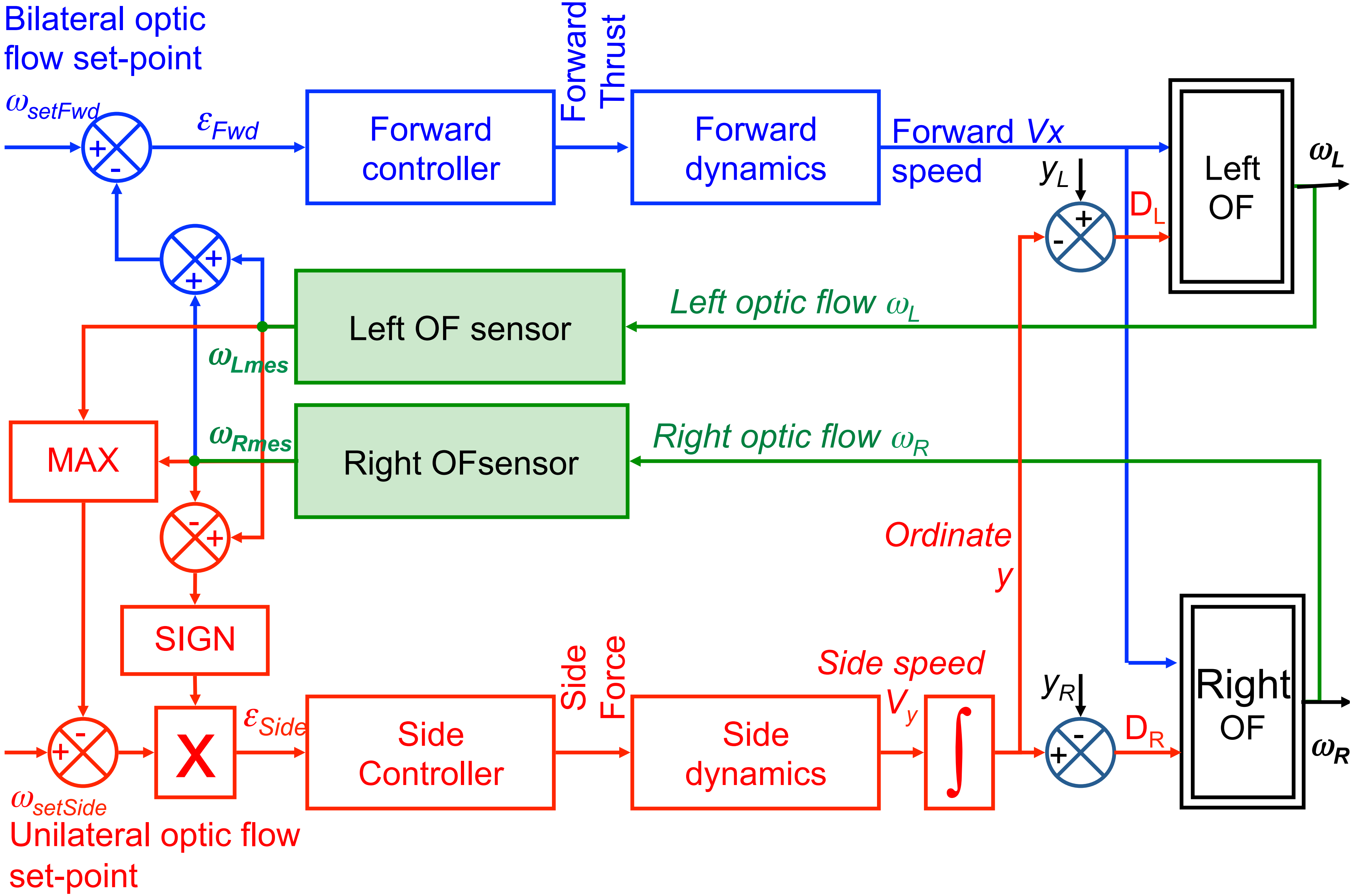
« Bees tend to keep their flight speed proportional to the corridor width »

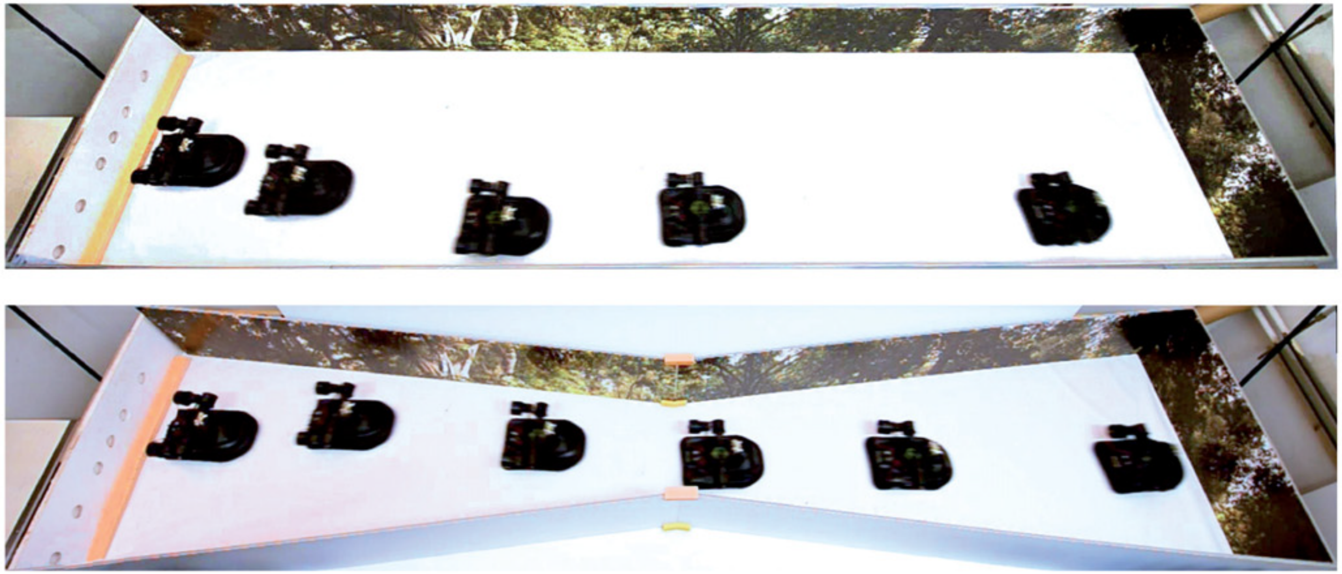
Conclusion:

« The speed of flight is controlled by regulating the image velocity »

Srinivasan et al. (1996)

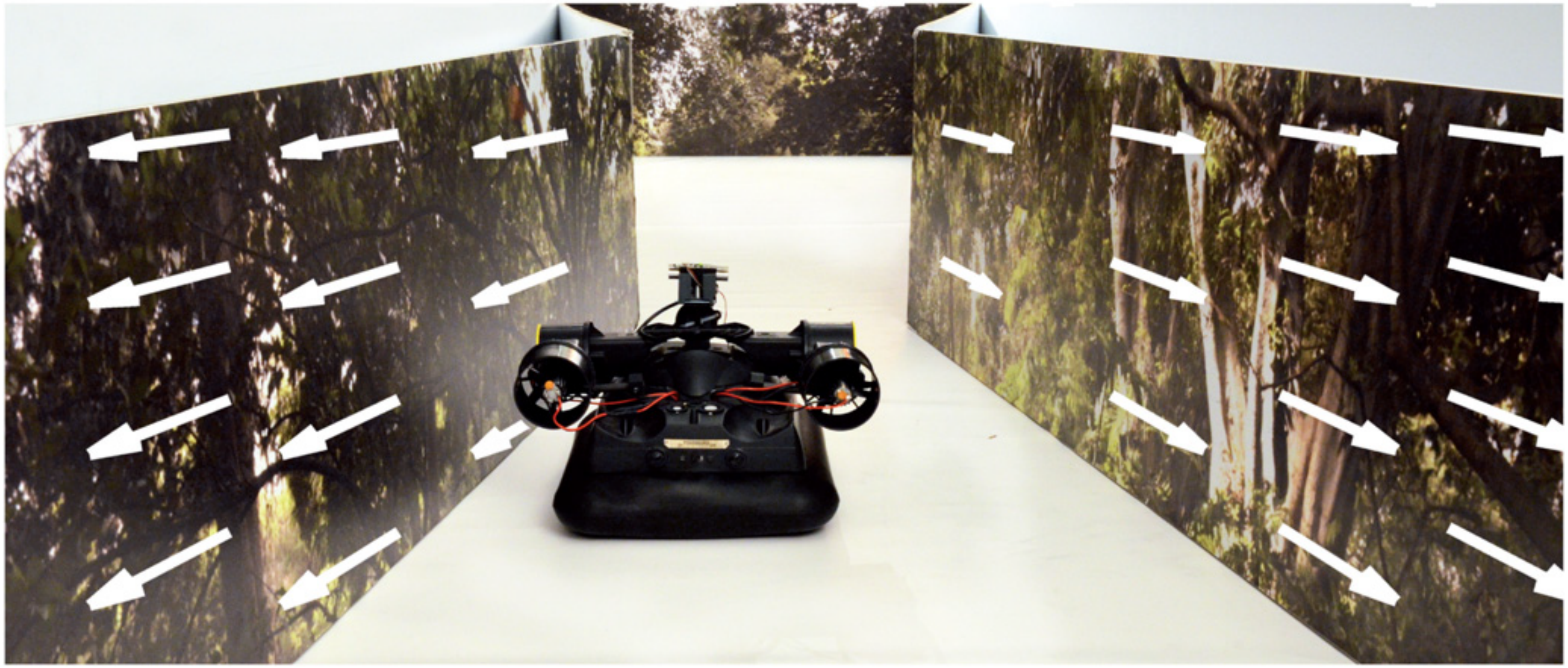
LORA III: Forward control loop+Side control loop



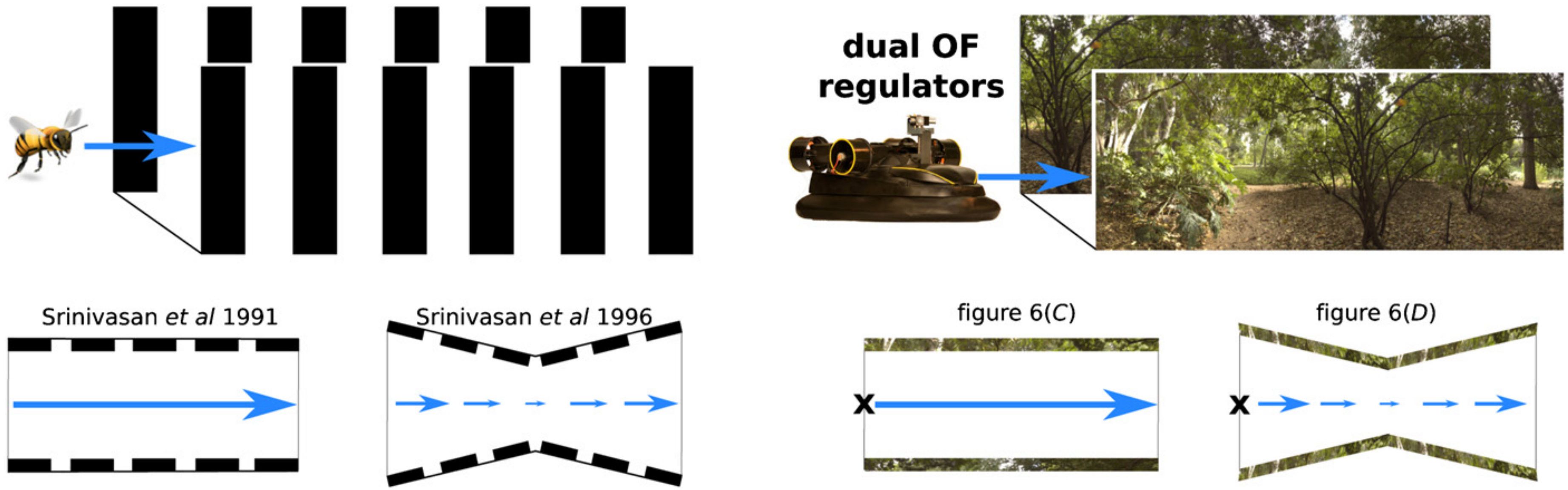


The robot LORA

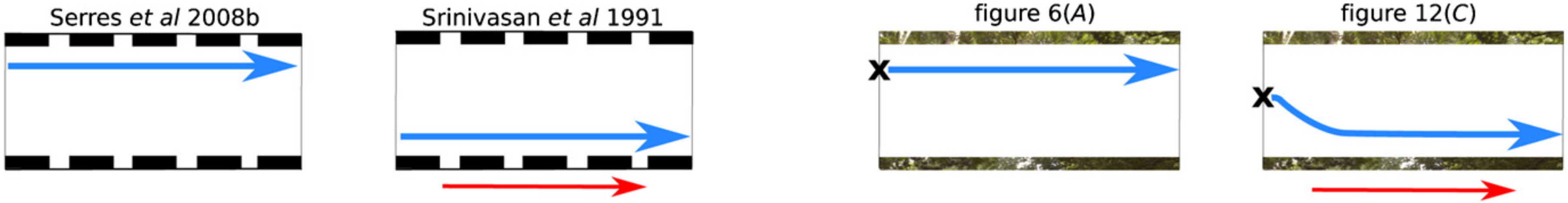
Roubieu et al. (2014)
Bioinspir. Biomim.



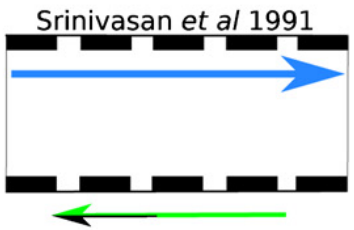
Roubieu et al. (2014) *Bioinspir. Biomim.*

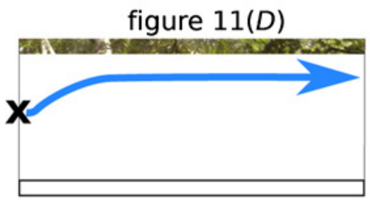


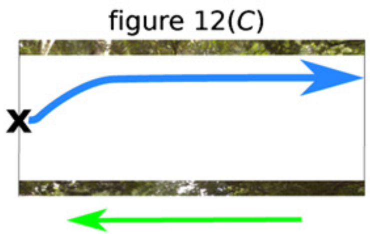
Roubieu et al. (2014) *Bioinspir. Biomim.*



Roubieu et al. (2014) *Bioinspir. Biomim.*

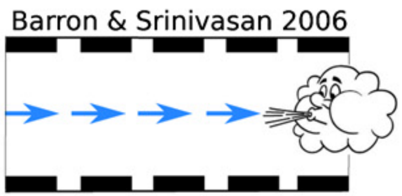






Roubieu et al. (2014) *Bioinspir. Biomim.*


dual OF
regulators


Barron & Srinivasan 2006

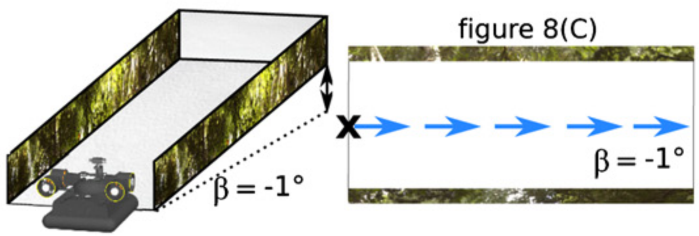
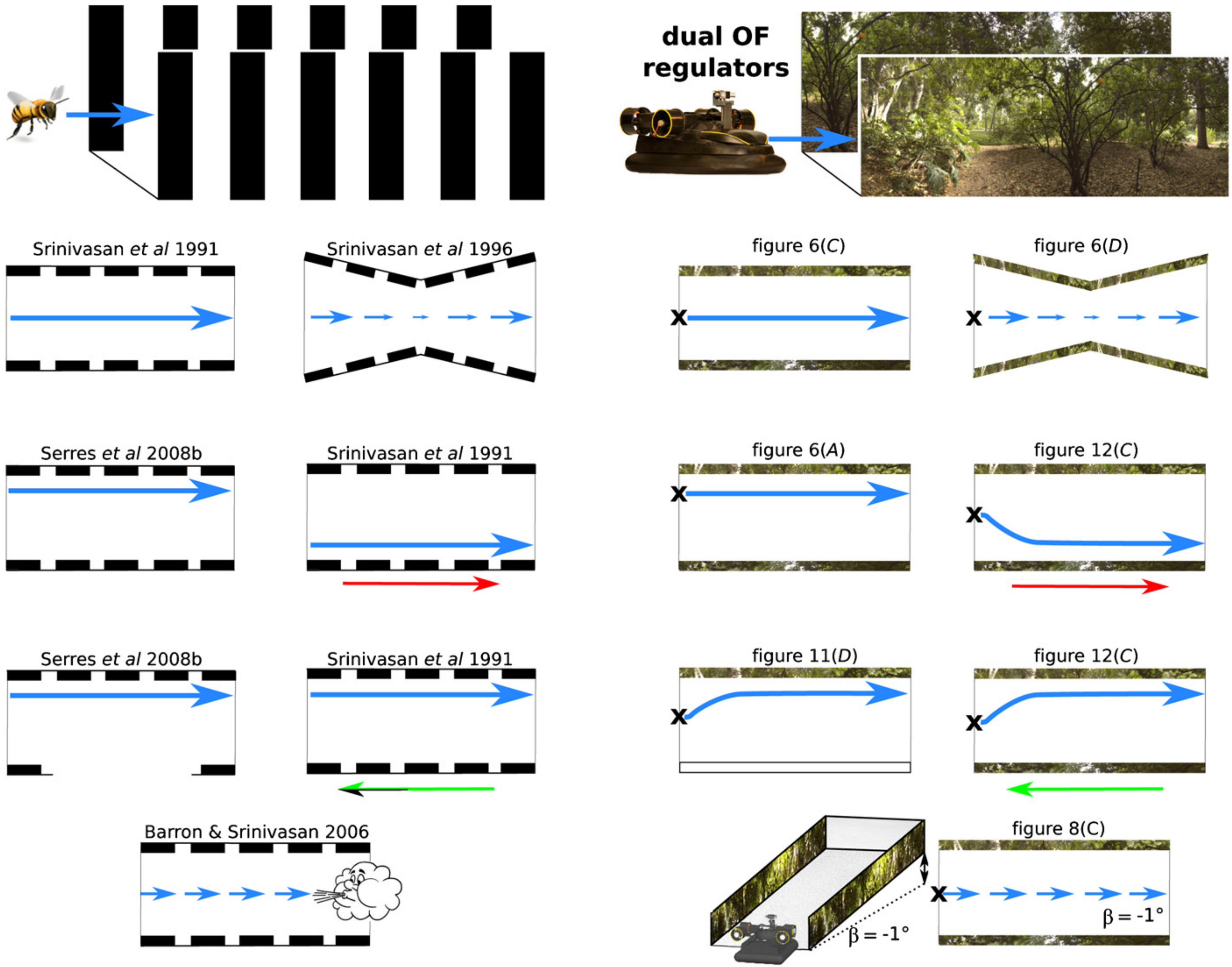


figure 8(C)
β = -1°
β = -1°



dual OF regulators
Srinivasan et al 1991
Srinivasan et al 1996
figure 6(C)
figure 6(D)
Serres et al 2008b
Srinivasan et al 1991
figure 6(A)
figure 12(C)
Serres et al 2008b
Srinivasan et al 1991
figure 11(D)
figure 12(C)
Barron & Srinivasan 2006
figure 8(C)
β = -1°
β = -1°

Dual optic flow regulation

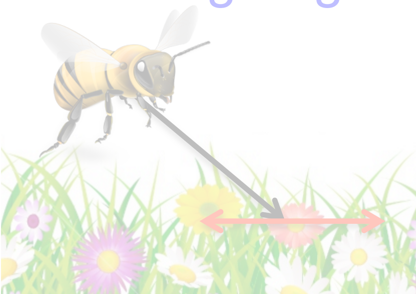
- Using Optic Flow regulation directly in a control loop that manipulates forces

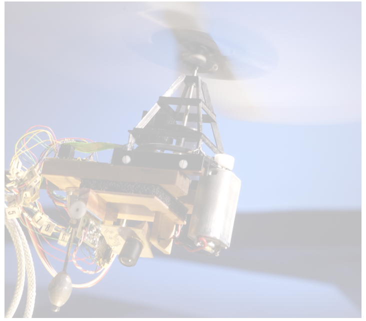
+ without measuring nor estimating states in any inertial frame of reference

$\Rightarrow$ The LORA robot mimics and accounts for insect behaviors

3 proof-of-concept robots based on optic flow => accounting for flying insect behaviors

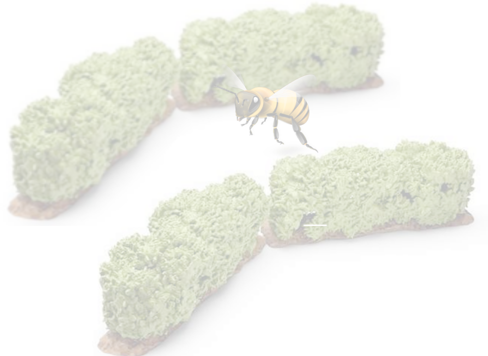
Flying with the wind and Landing on a moving target





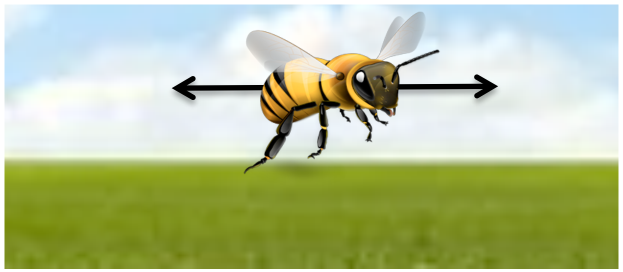
Ruffier, Franceschini (2005, 2014)

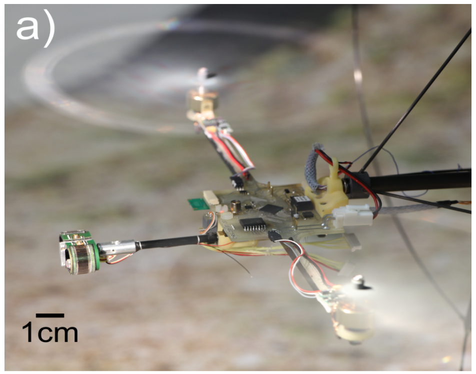
Position and speed control in narrow corridor



Roubieu et al. (2014) Bioinsp. Biomim.

Stabilize pitch without IMU nor accelerometer

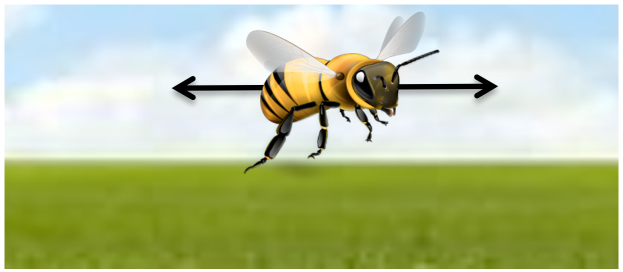


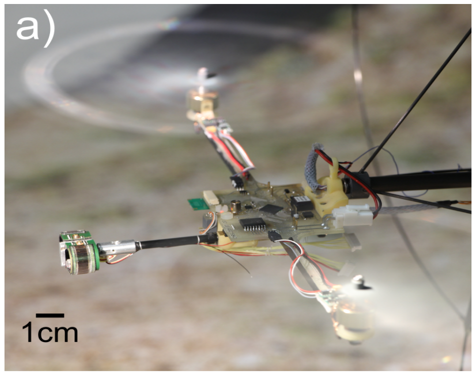


Expert, Ruffier (2015) B&B Accepted

⟹ Beerotor

Stabilize pitch without IMU nor accelerometer





Expert, Ruffier (2015) B&B Accepted

⟹ Beerotor

Almost all aircraft use the inertial reference frame

Commercial aircraft, helicopter, quadrirotor, …

⇒ use Inertial Measurement Unit,

⇒ use the absolute vertical,

⇒ control their attitude in the inertial reference frame, i.e. with respect to the center of the Earth

In insect, compound eye and ocelli are used as horizon detector:

⇒ Pb: Might not be very helpful indoors or under the canopy

⇒ But still, insects fly very well indoors or under the canopy

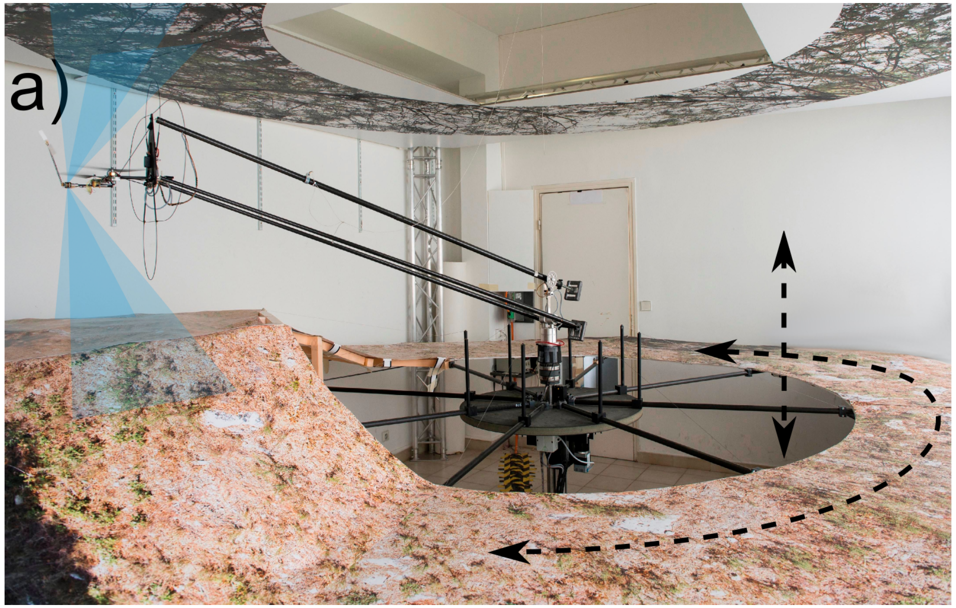
As far as I know, only Dipteria (and Strepsiptera) are endowed with inertial modalities:

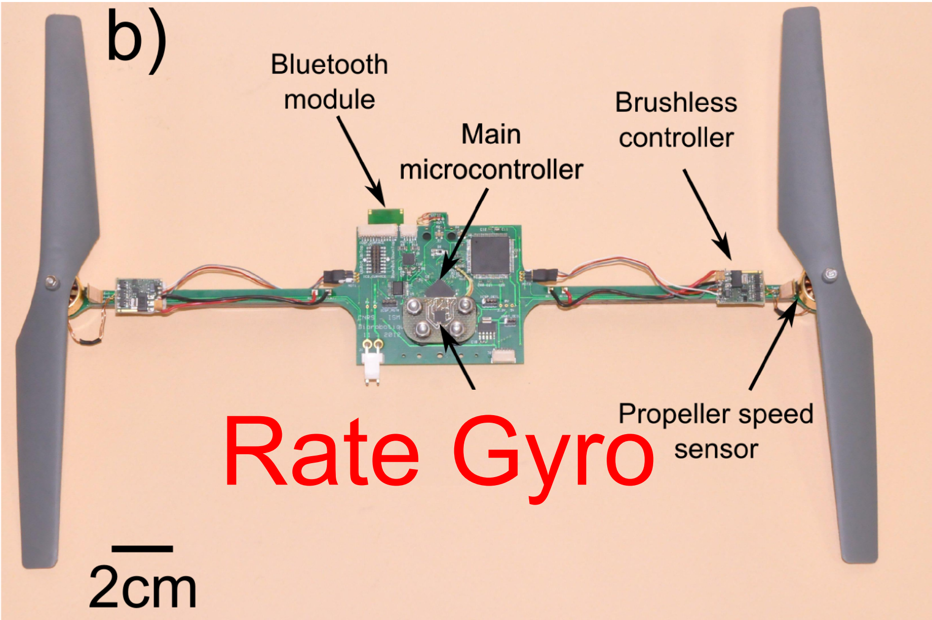
⇒ Pb: no absolute attitude as their halteres act as rate gyro

⇒ Very little evidence that some organ may serve as accelerometer

Beerotor: Flying over uneven moving terrain based on optic-flow cues

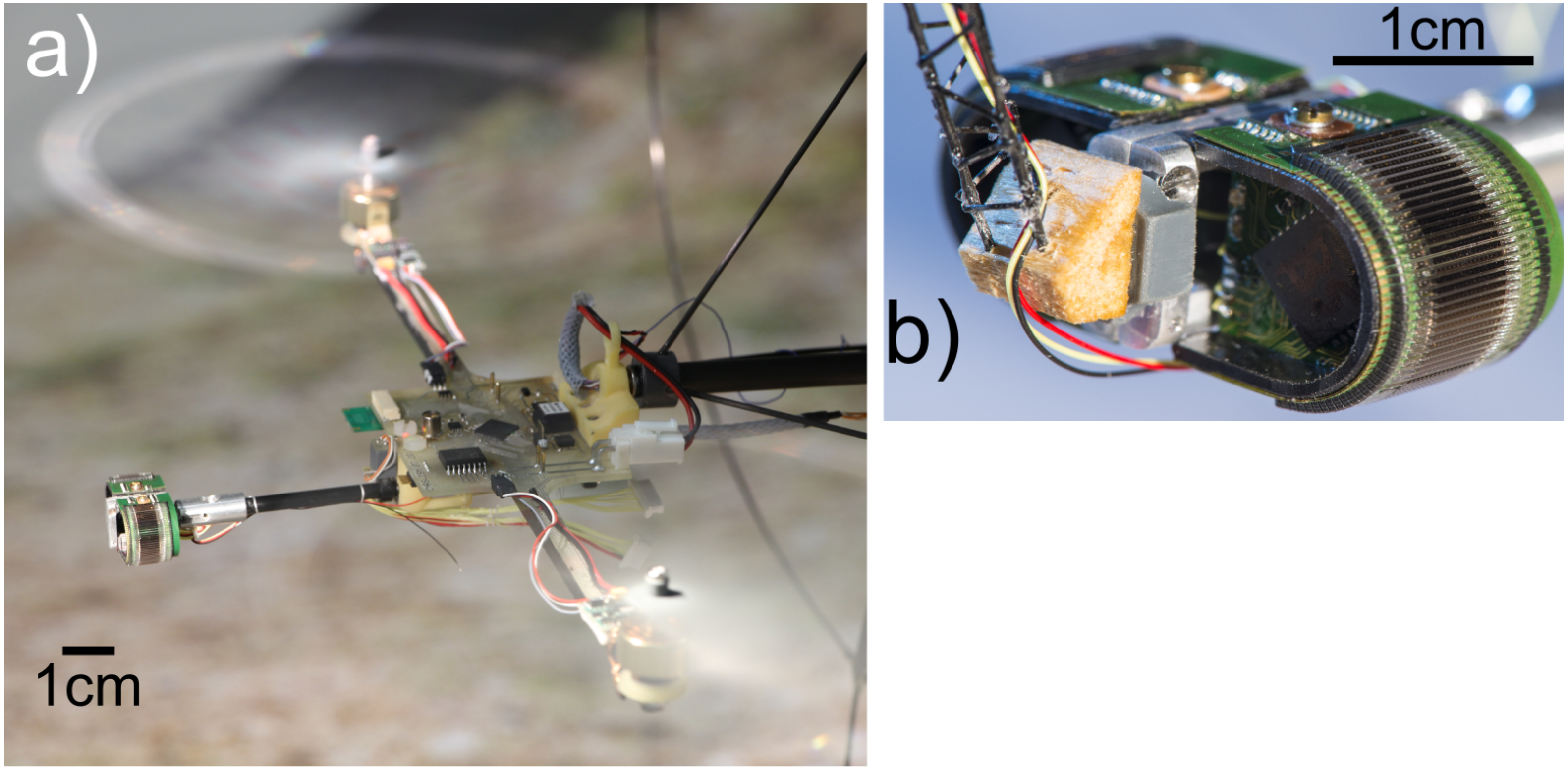
3 degrees-of-freedom
aerial robot





without using the inertial reference frame or accelerometer

Expert, Ruffier (2015) B&B

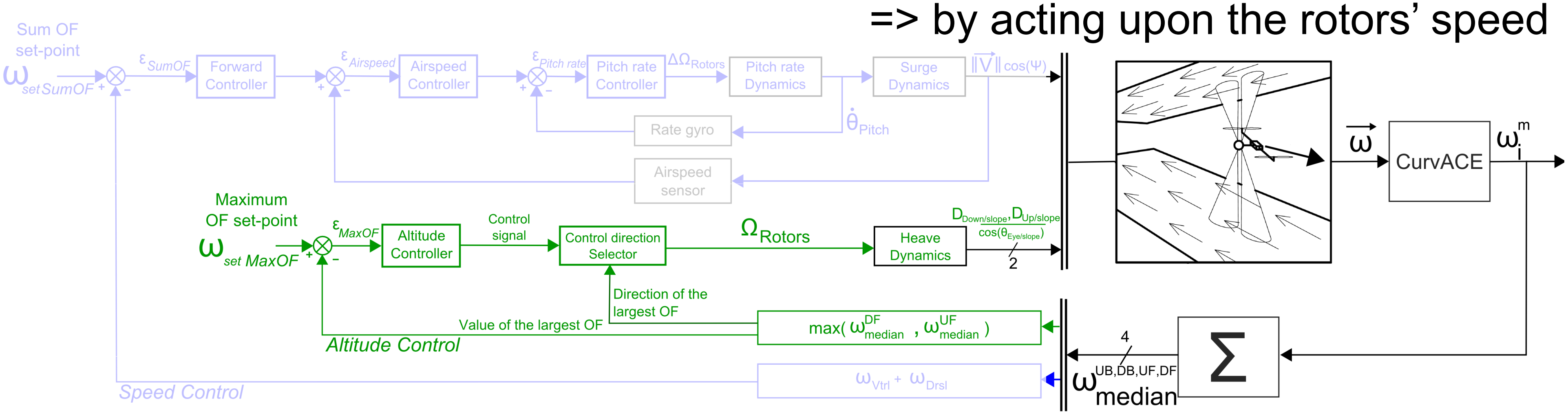


Expert, Ruffier (2015) B&B

1st control law:

To regulate the maximum optic flow (ventral or dorsal)

=> by acting upon the rotors' speed

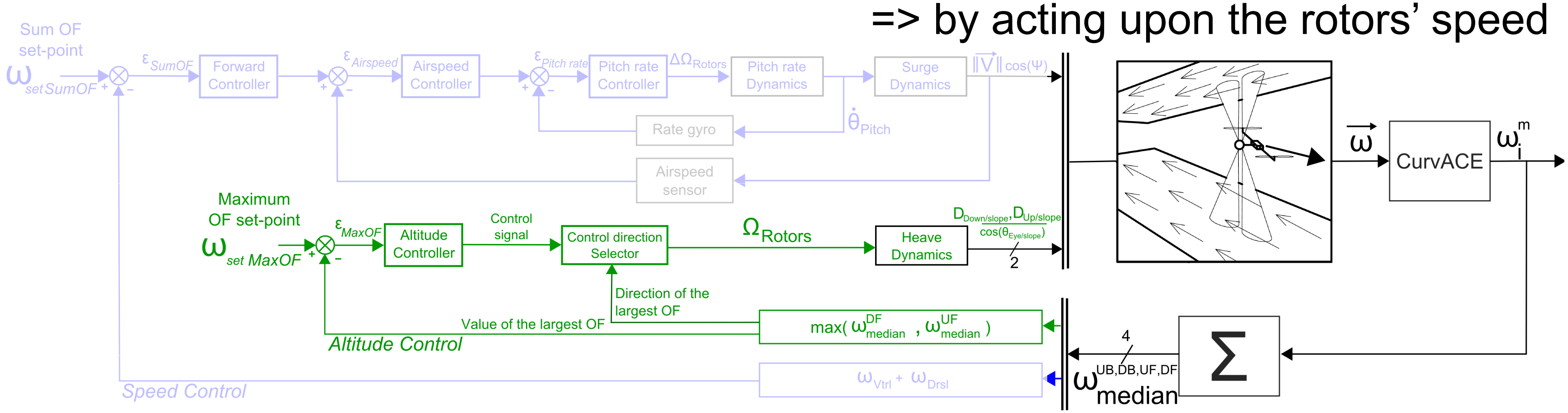


Expert, Ruffier (2015) B&B

1st control law:

To regulate the maximum optic flow (ventral or dorsal)

=> by acting upon the rotors' speed

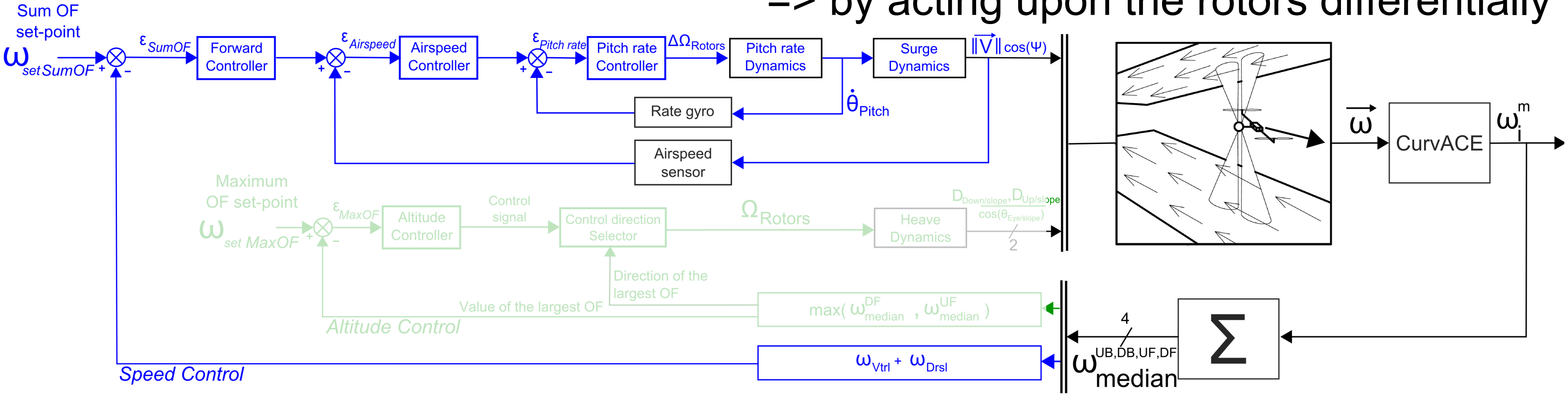


Expert, Ruffier (2015) B&B

2nd control law:

To regulate the sum of ventral + dorsal optic flow

=> by acting upon the rotors differentially

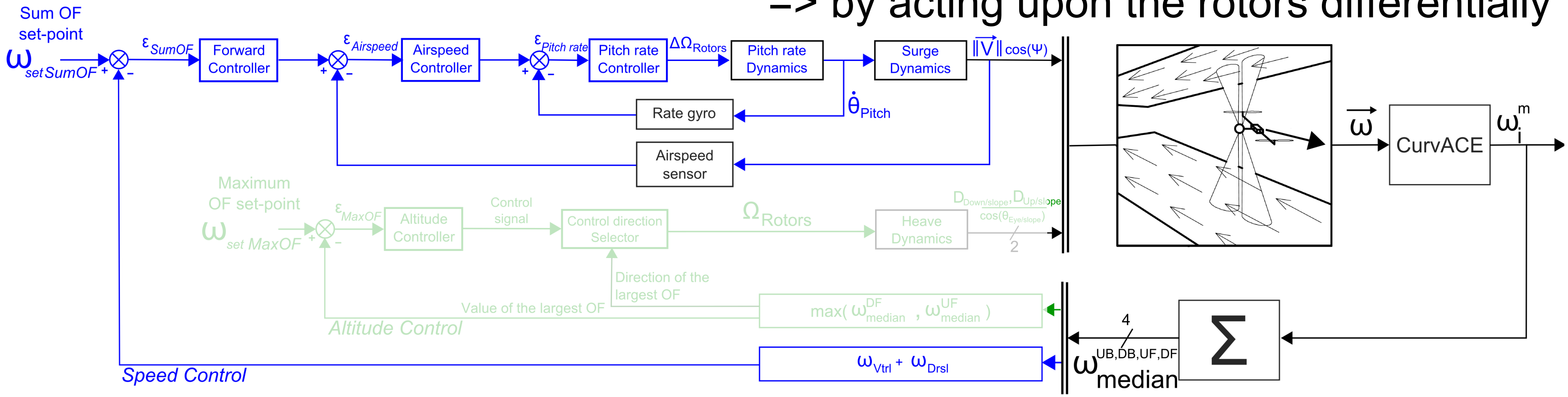


Expert, Ruffier (2015) B&B

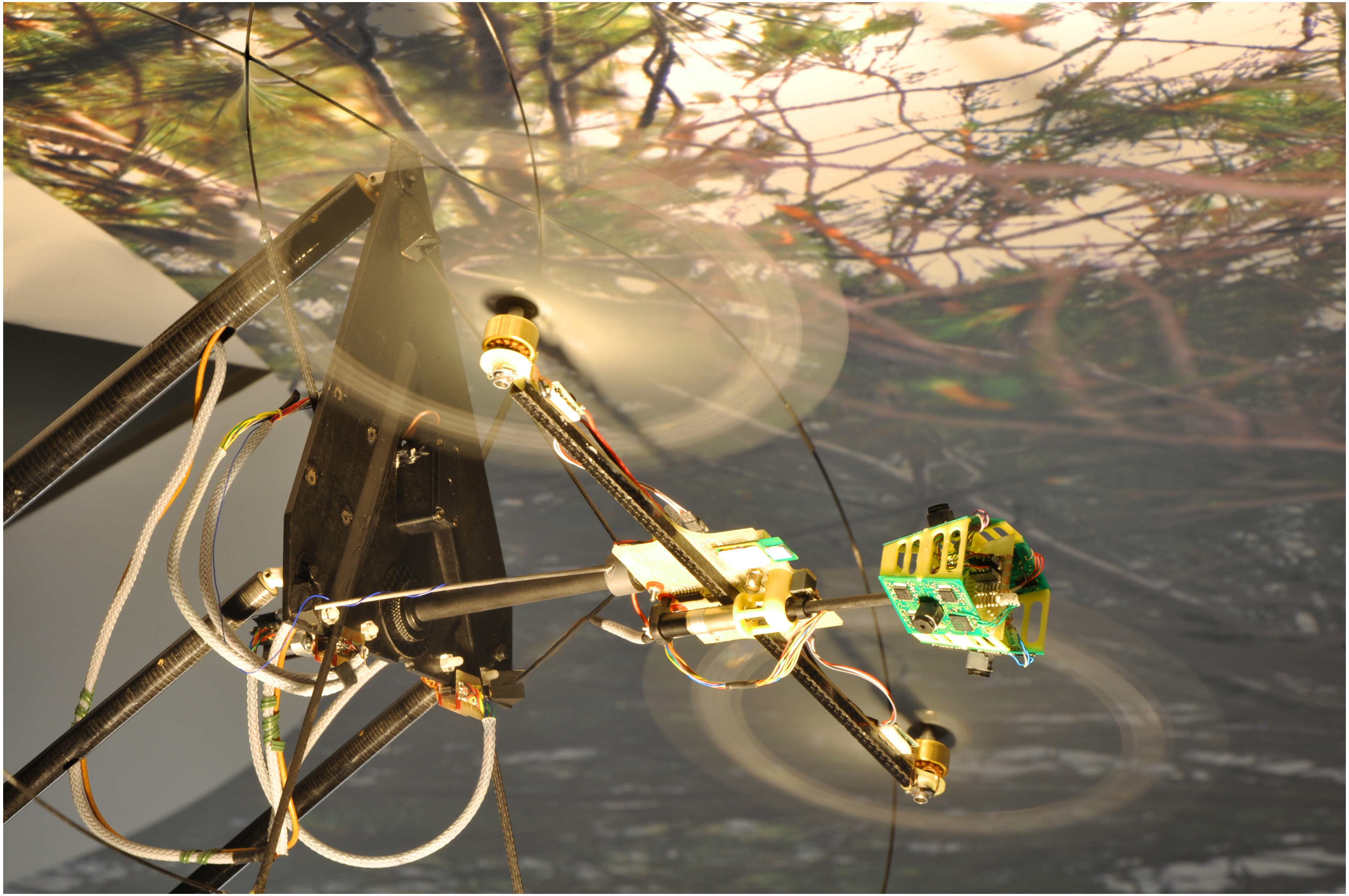
2nd control law:

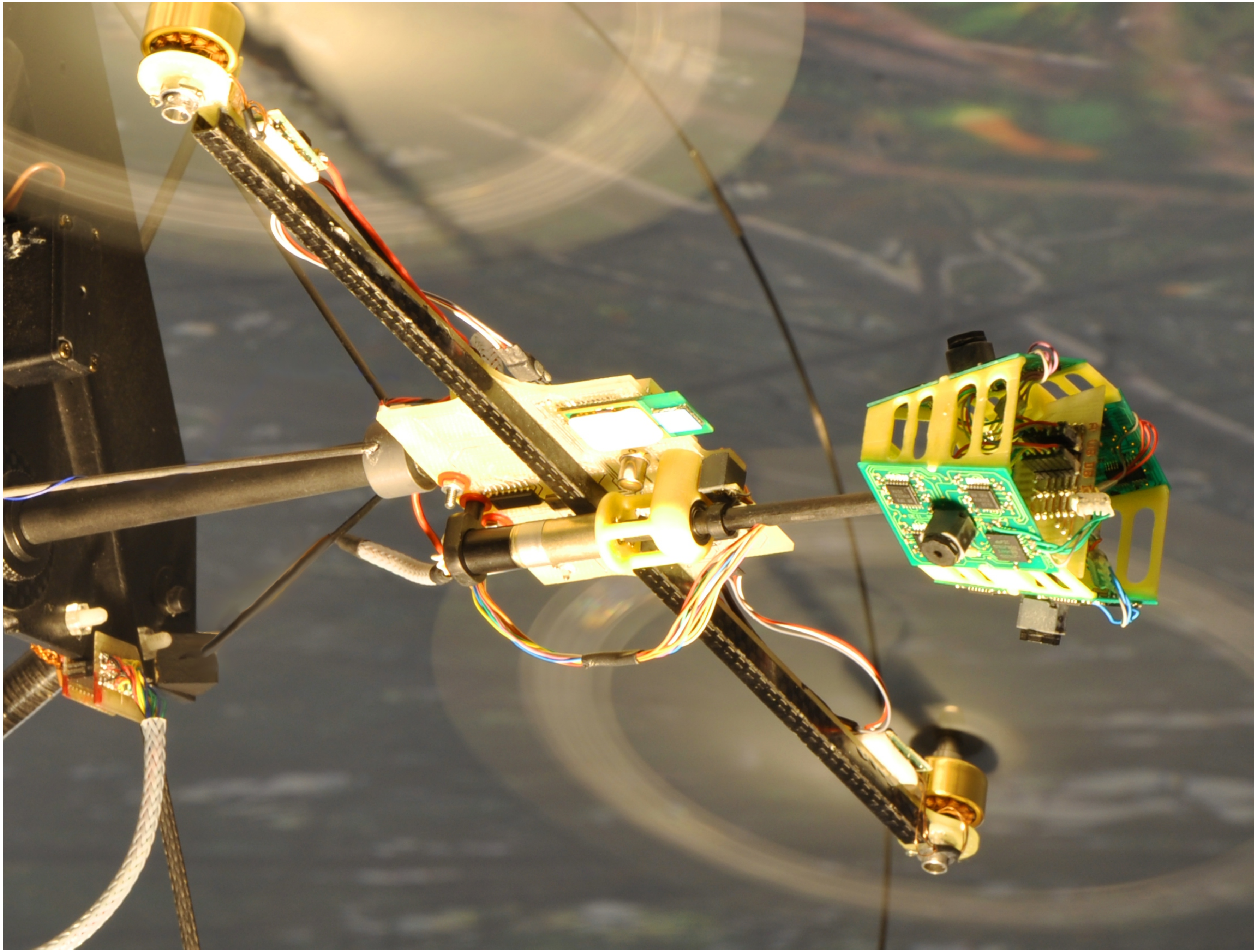
To regulate the sum of ventral + dorsal optic flow

=> by acting upon the rotors differentially

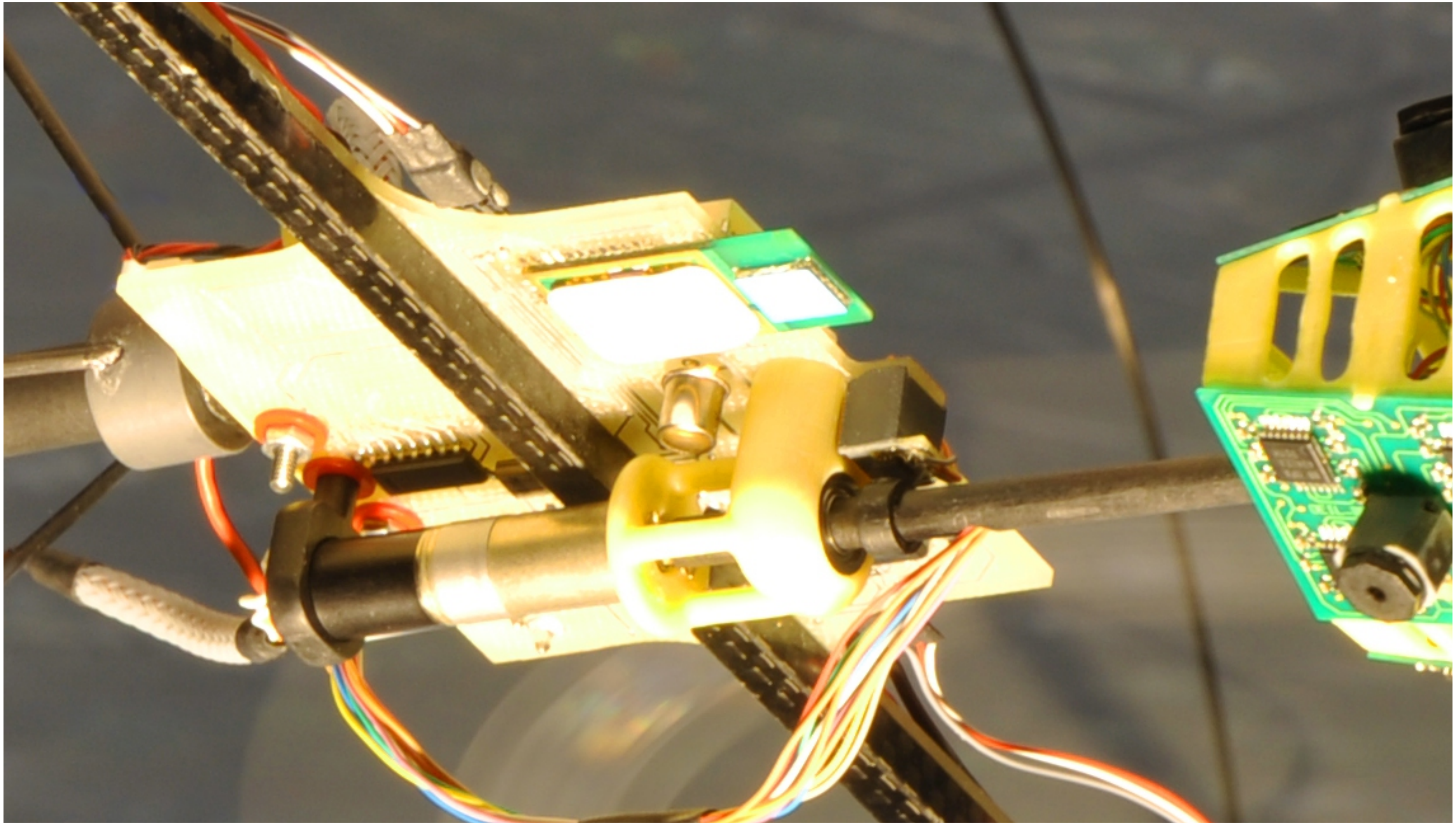


Expert, Ruffier (2015) B&B



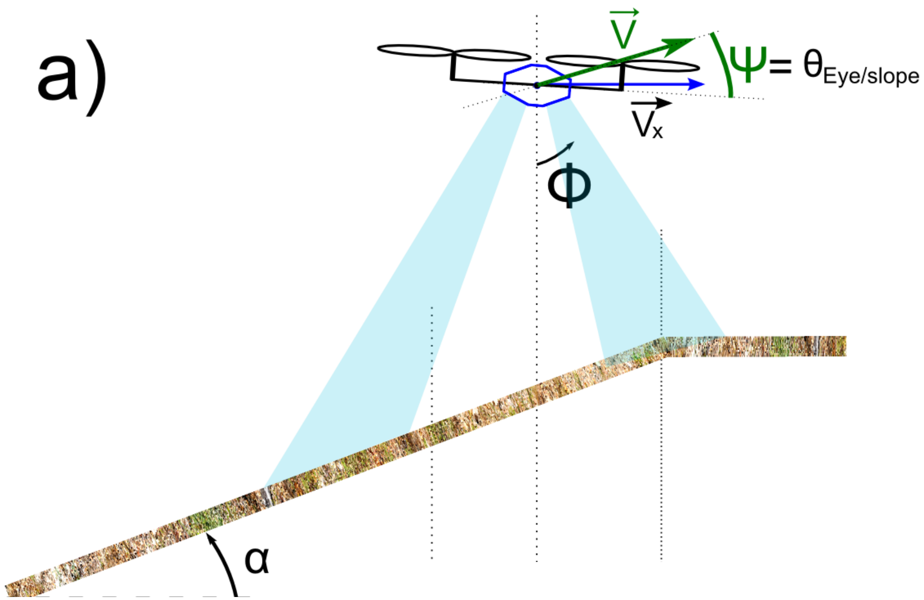


A motor decoupling eye rotation from body rotation

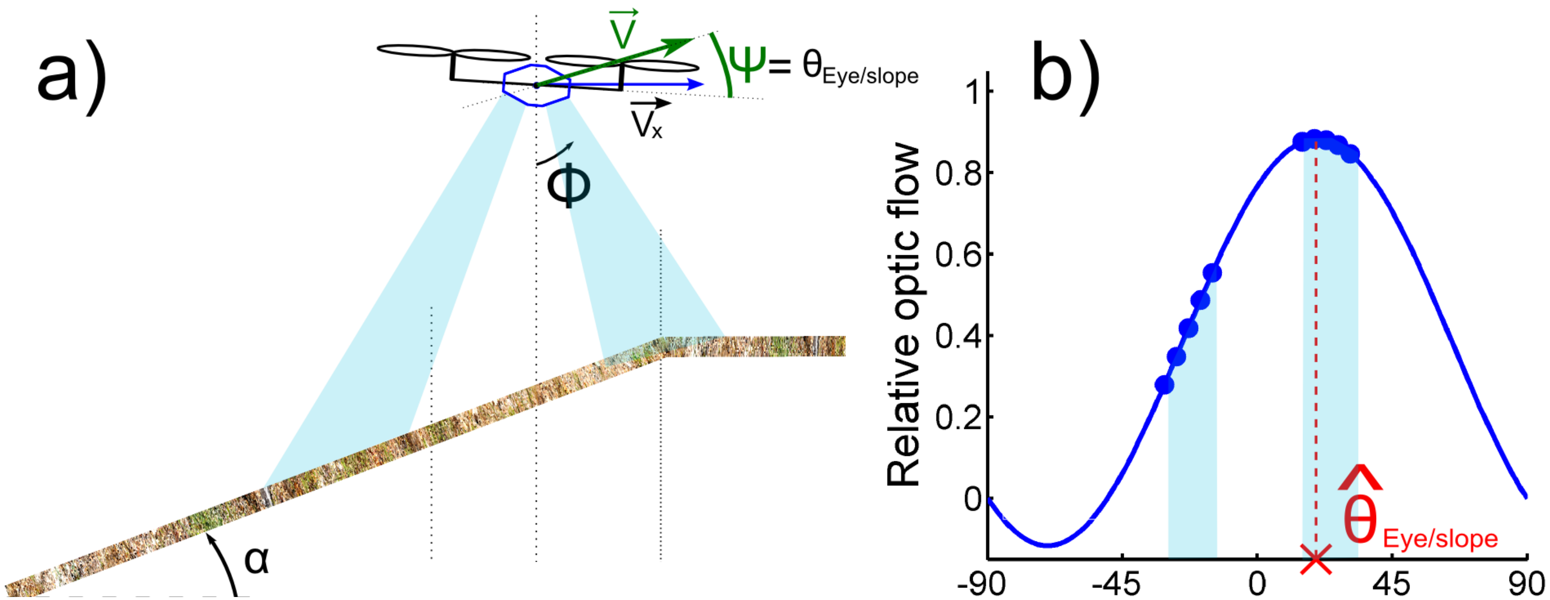


=> The idea is to reorient the eye during the flight

Without eye reorientation, the OF depends on the angle between the eye and the slope which causes the crash



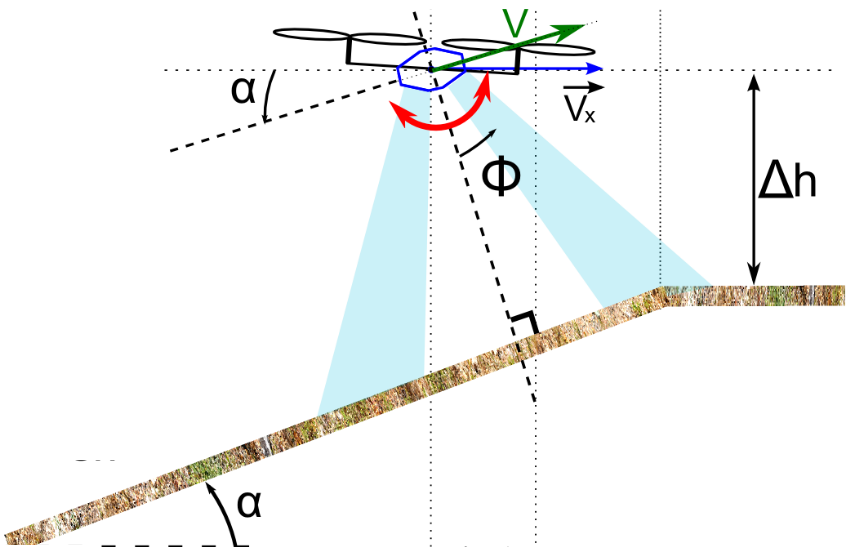
Without eye reorientation, the OF depends on the angle between the eye and the slope which causes the crash

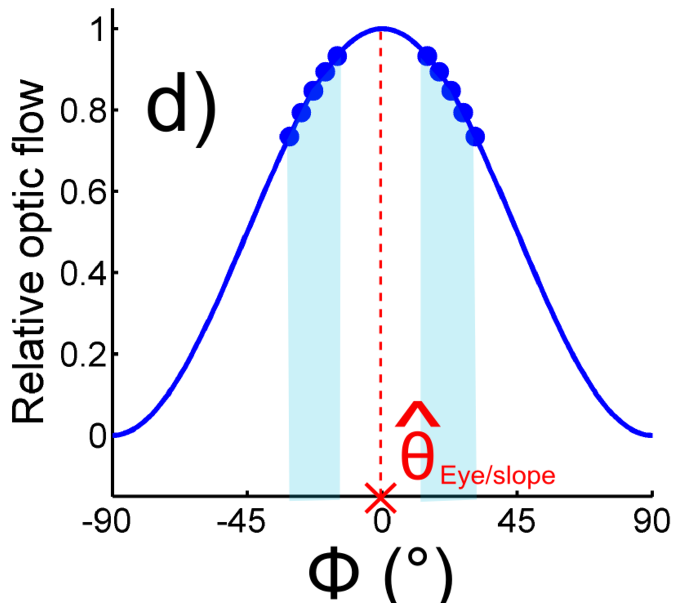


3rd control law:

To orient the OF sinus profile toward surface below

=> by acting upon the eye's pitch

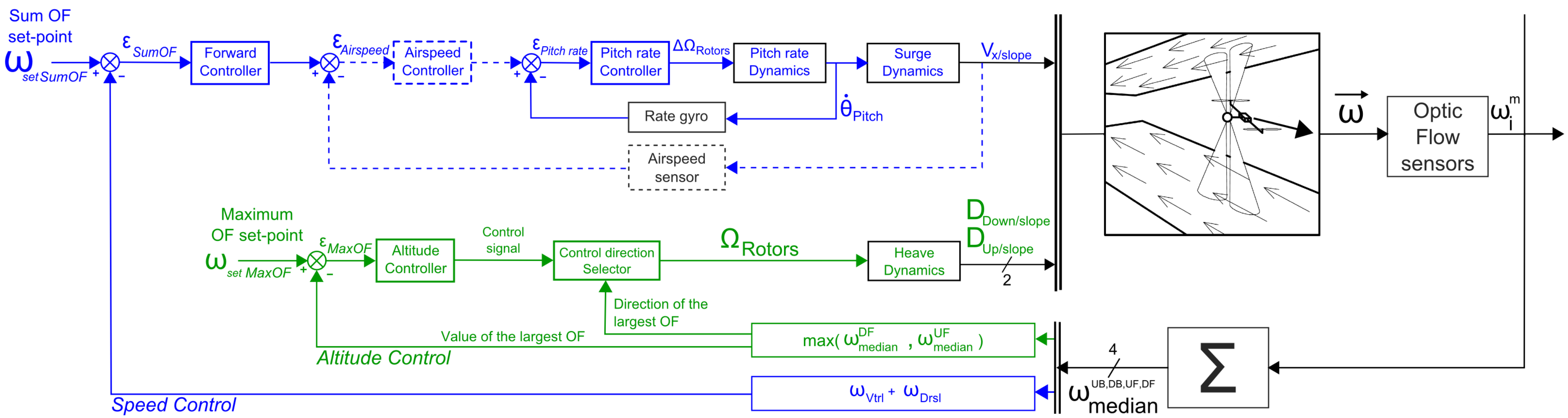




3rd control law:

To orient the OF sinus profile toward surface below

=> by acting upon the eye's pitch

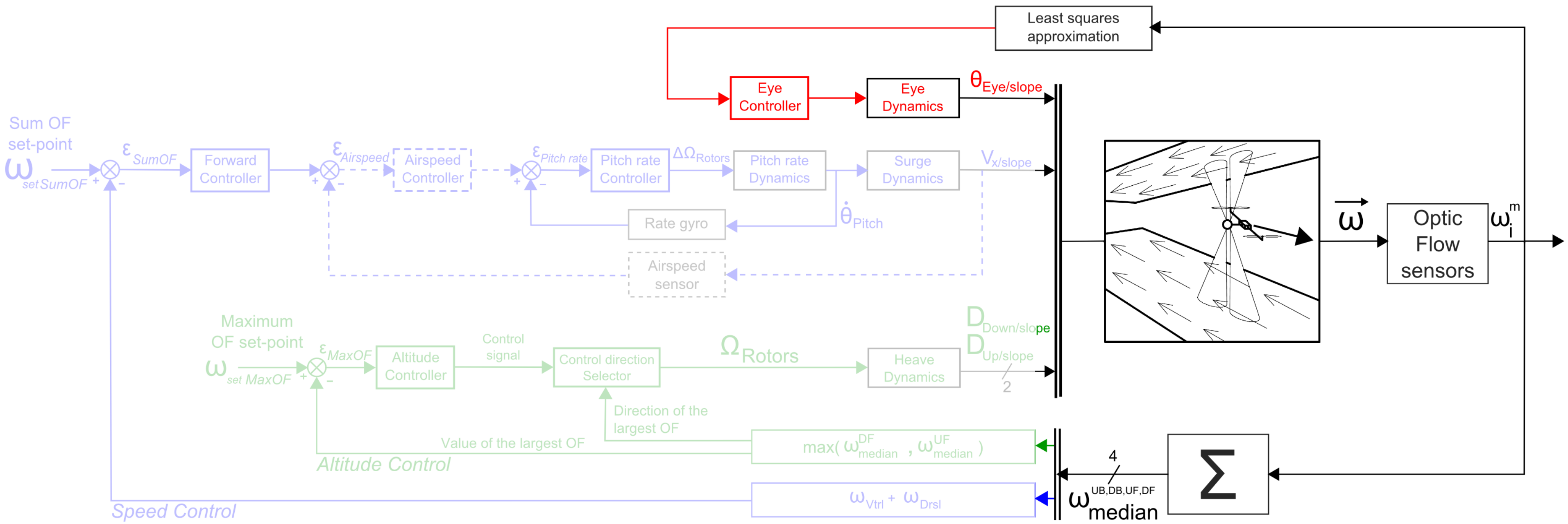


Expert, Ruffier (2015) Accepted

3rd control law:

To orient the OF sinus profile toward surface below

=> by acting upon the eye's pitch



Expert, Ruffier (2015) Accepted

Thanks to :

Nicolas Franceschini

Stephane Viollet

Julien Serres

Fabien Expert

Frederic Roubieu

Geoffrey Portelli

Marc Boyron

Julien Diperi