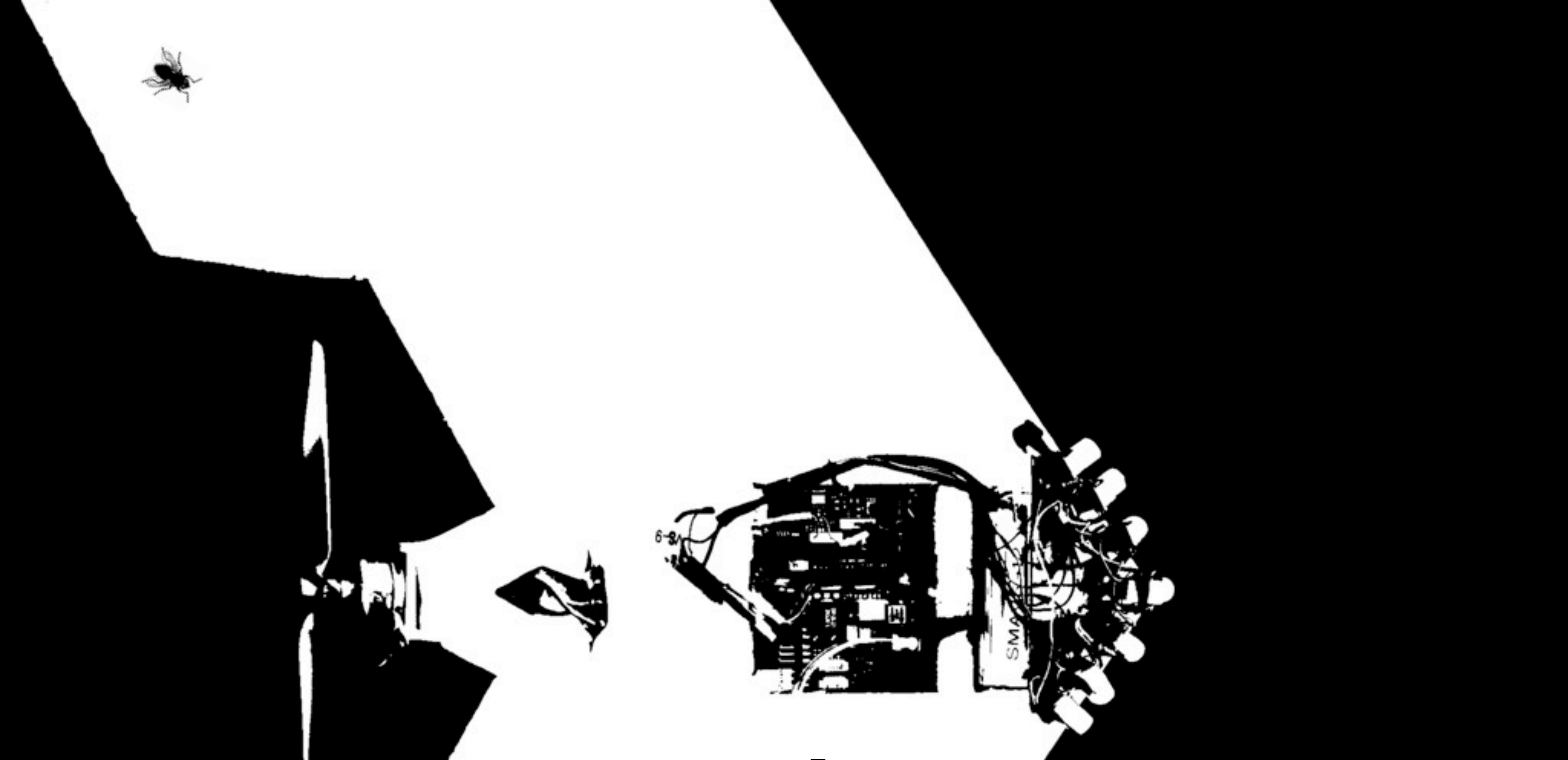

optiPilot

low altitude flight and collision avoidance

The problem at hand







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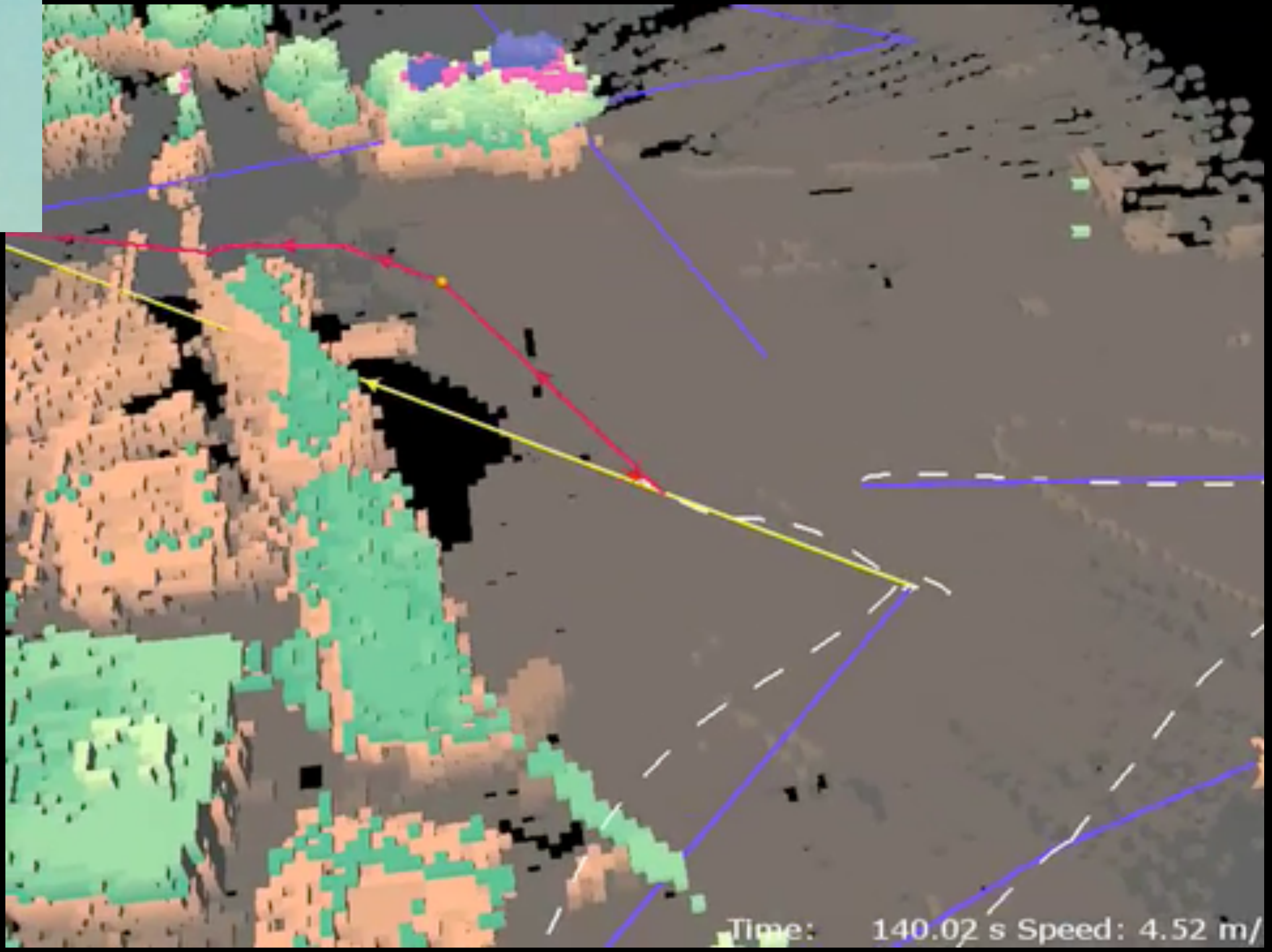
The classical approach

Scherer et al., CMU



- 3D mapping of the environment
- 75 kg Yamaha helicopter
- 2D scanning LIDAR (3 kg)
- GPS+IMU-based low level control

=> heavy sensors

=> significant computational power & memory

How do flying insects solve that problem?

- No 3D map of their environment and no GPS

- No active distance sensors, but:
  - low-resolution, fast, 360° vision (optic flow)
  - rate gyros
  - airspeed

- Mostly reactive control

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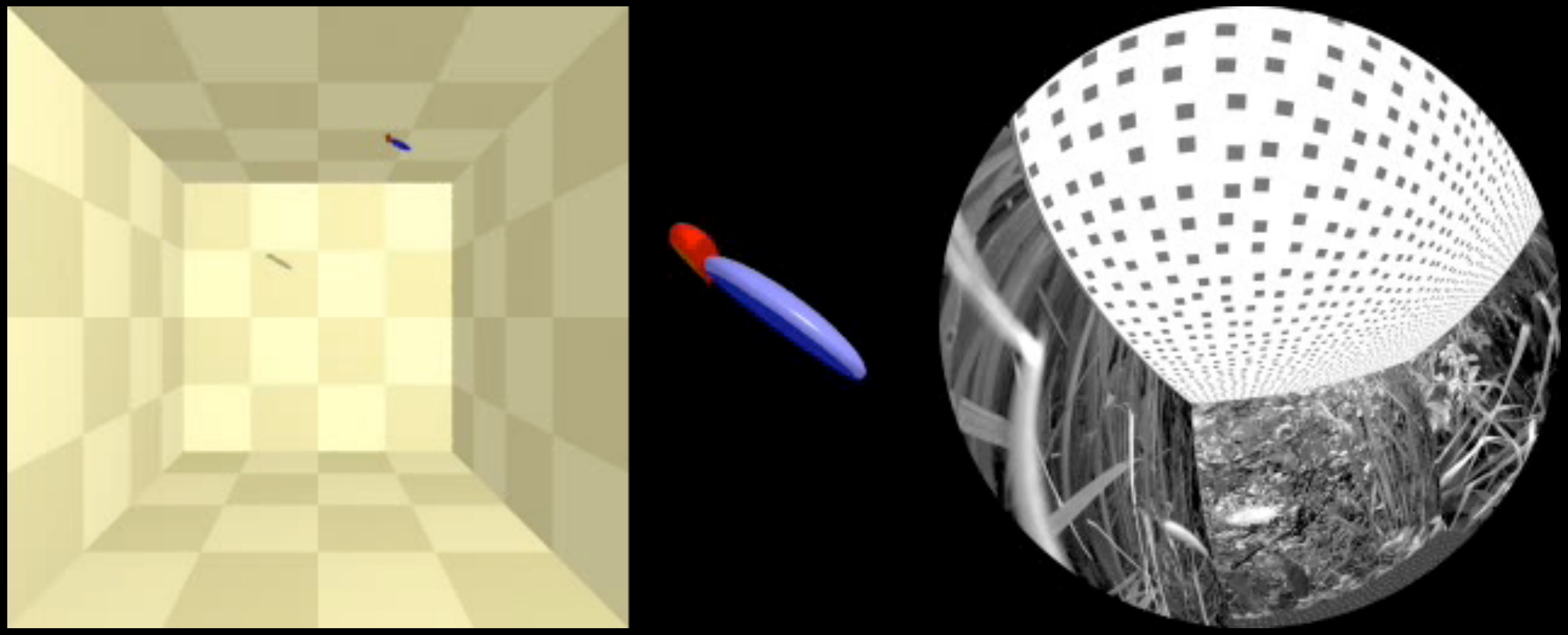
How to turn optic flow into proximity estimates?

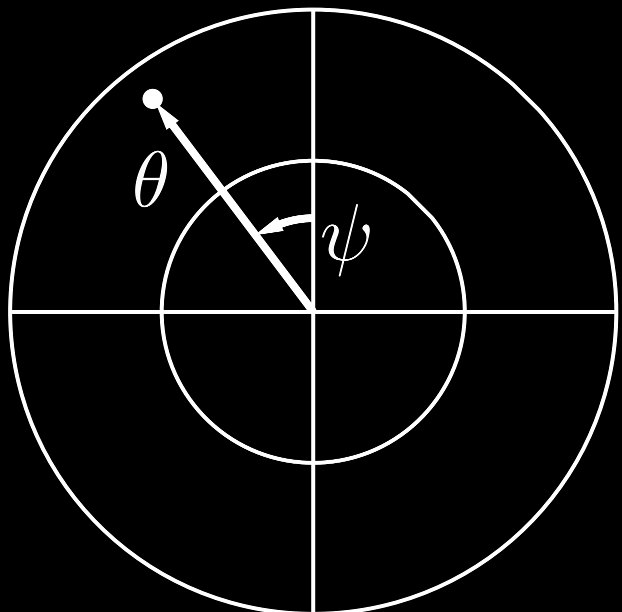
- Derotation
- Motion constraints
  - orientation of translation vector
  - amplitude of translation vector



Kern, R., van Hateren, J.H., Michaelis, C., Lindermann, J.P., Egelhaaf, M.
PLOS Biology, 2005

- Chose the right viewing directions
- Assumptions: no wind, static environment
- Let's consider a spherical camera model...

Optic-flow-based proximity estimation

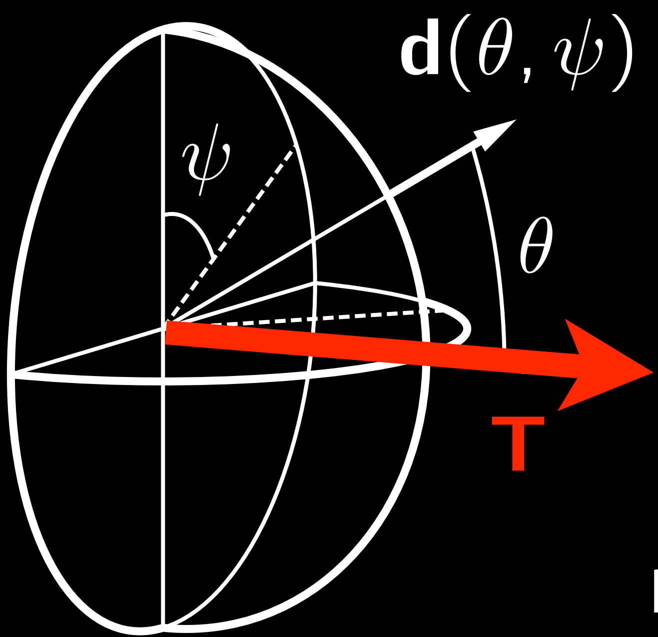


translational optic flow | rotational optic flow

$$\mathbf{p}(\theta,\psi) = \underbrace{\frac{\mathbf{T} - (\mathbf{T}\cdot\mathbf{d}(\theta,\psi))\cdot\mathbf{d}(\theta,\psi)}{D(\theta,\psi)}}_{\mathbf{p}_\mathrm{T}(\theta,\psi)} \underbrace{- \mathbf{R}\times\mathbf{d}(\theta,\psi)}_{\mathbf{p}_\mathrm{R}(\theta,\psi)}$$

translations are difficult to measure, but predictable in translation flight

rotations can be measured from rate gyroscopes



Motion parallax

$$p_\mathrm{T} = \frac{|\mathbf{T}|}{D}\cdot\sin\angle(\mathbf{T},\mathbf{d}) \qquad \angle(\mathbf{T},\mathbf{d}) = \theta$$

Proximity estimation

$$\mu(\theta,\psi) = \frac{1}{D(\theta,\psi)} = \frac{p_\mathrm{T}(\theta,\psi)}{|\mathbf{T}|\cdot\sin\theta}$$

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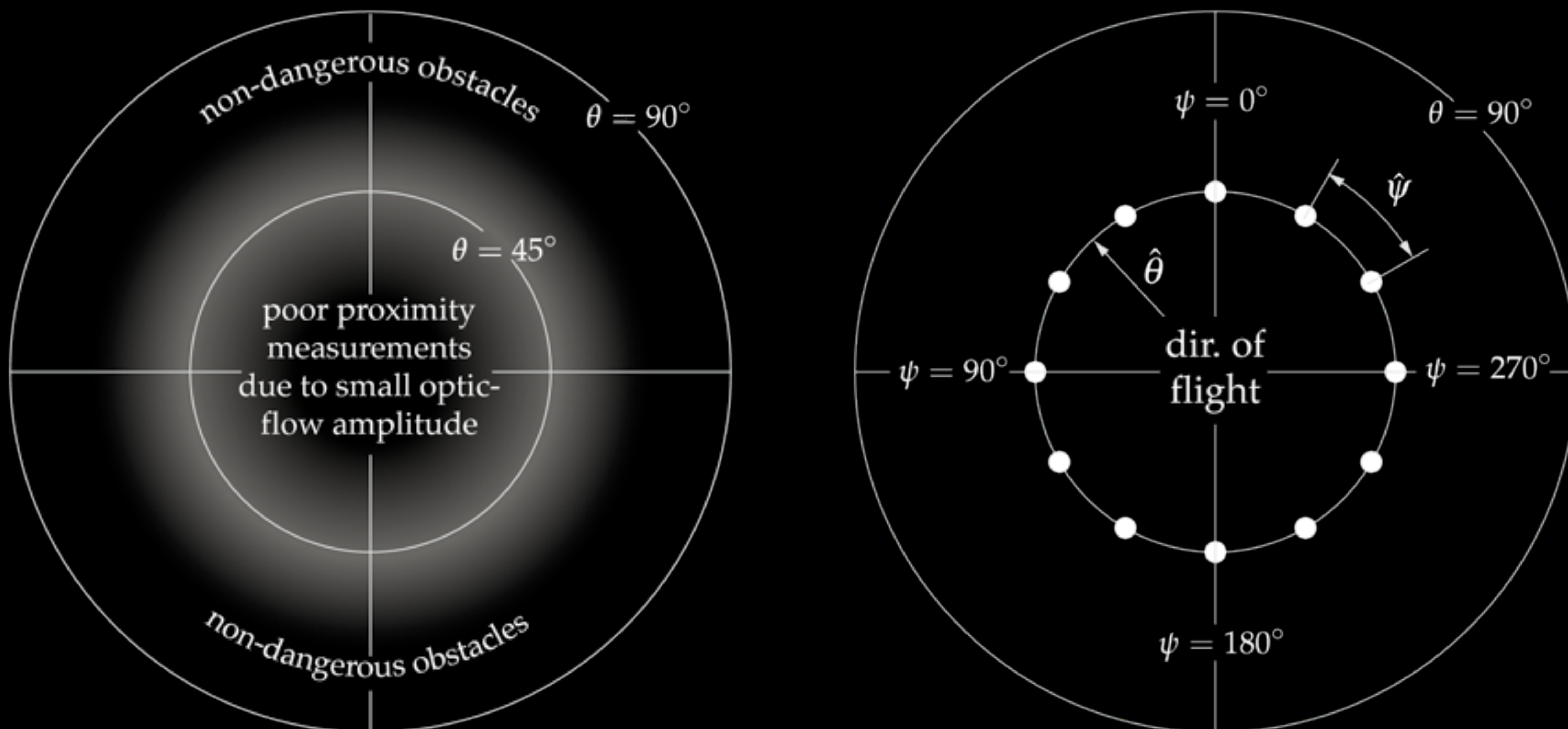
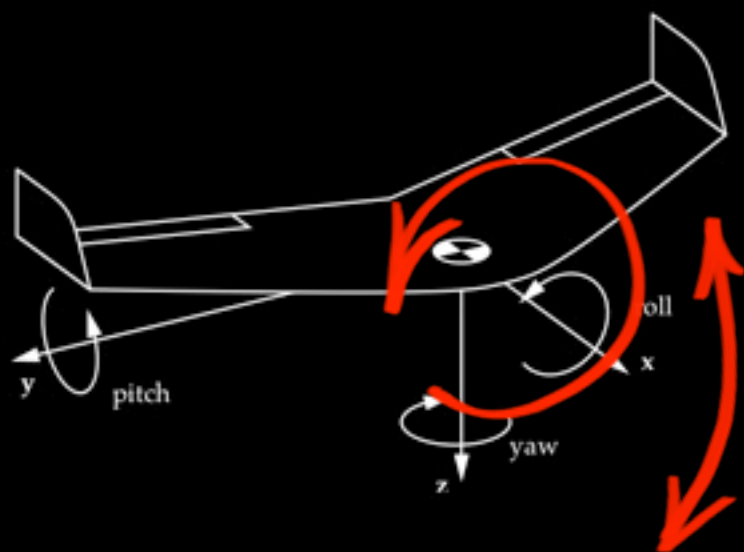
LIS

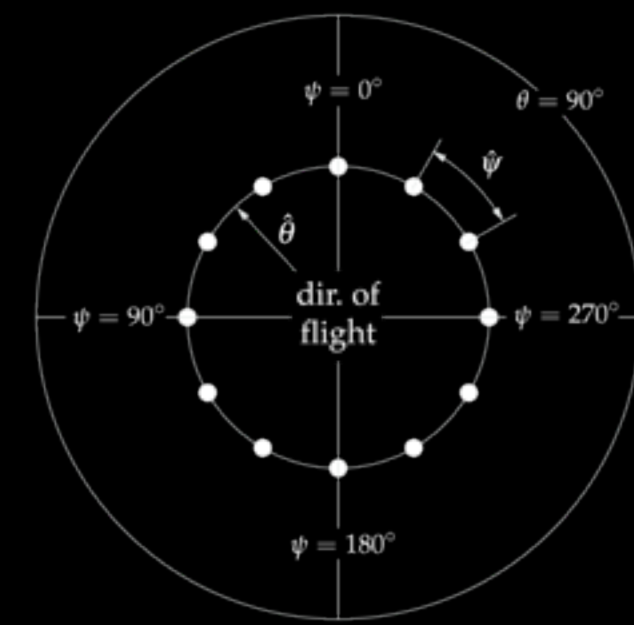
Choice of viewing direction

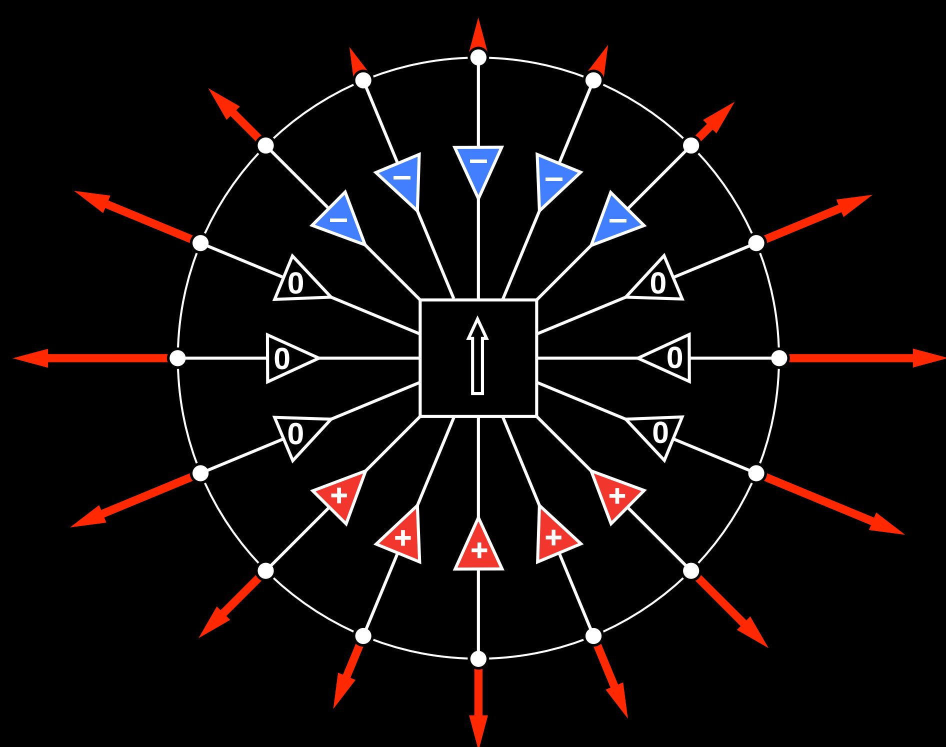


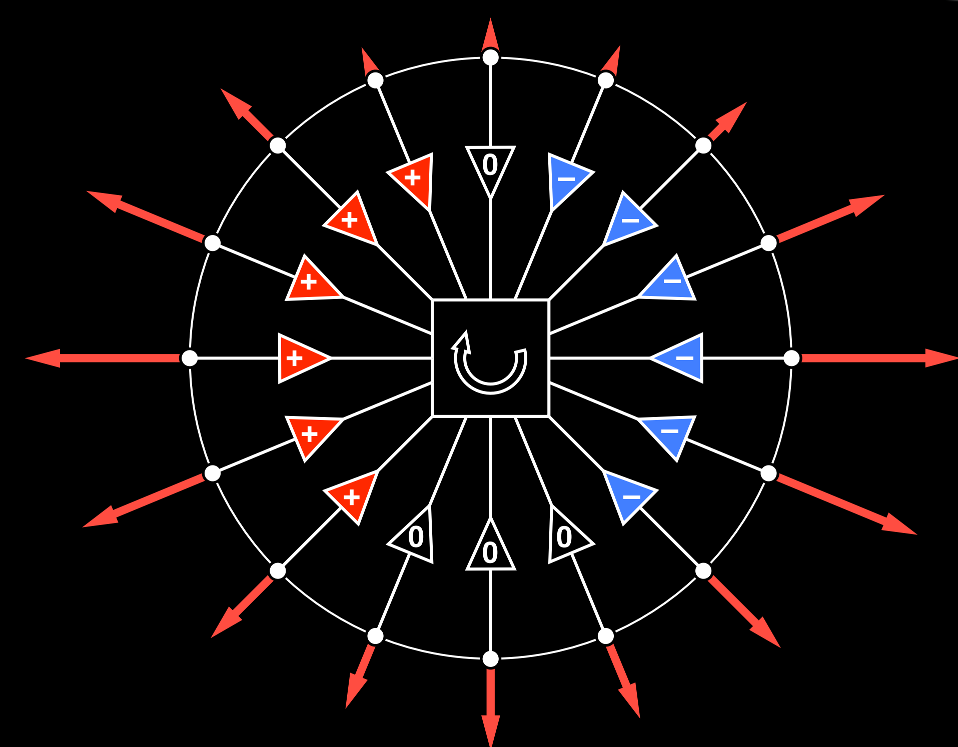
Control signal generation



$$c = \frac{K}{N \cdot \sin\hat{\theta}} \sum_{k=0}^{N-1} p_{\mathrm{T}}(\hat{\theta}, k \cdot \hat{\psi}) \cdot w_k$$







Beyeler, A., Zufferey, J.-C. and Floreano, D. Vision-based control of near-obstacle flight.
Autonomous Robots, 2009.

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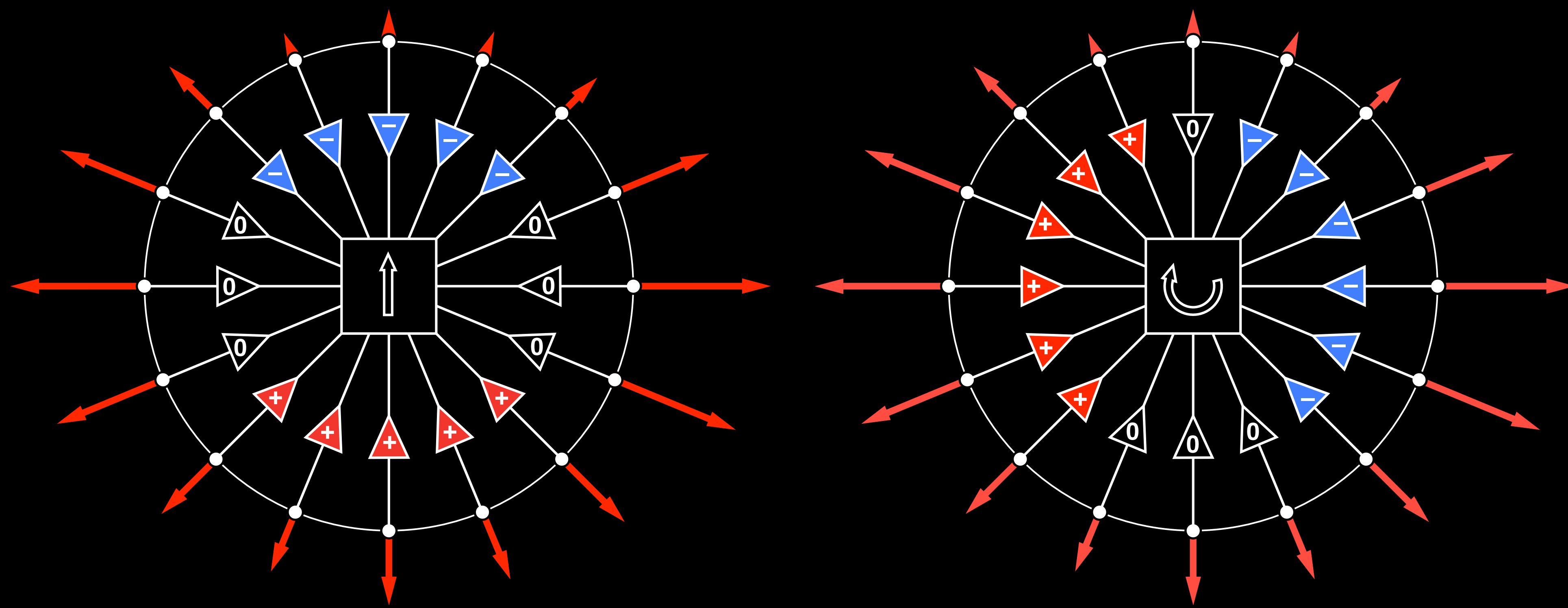
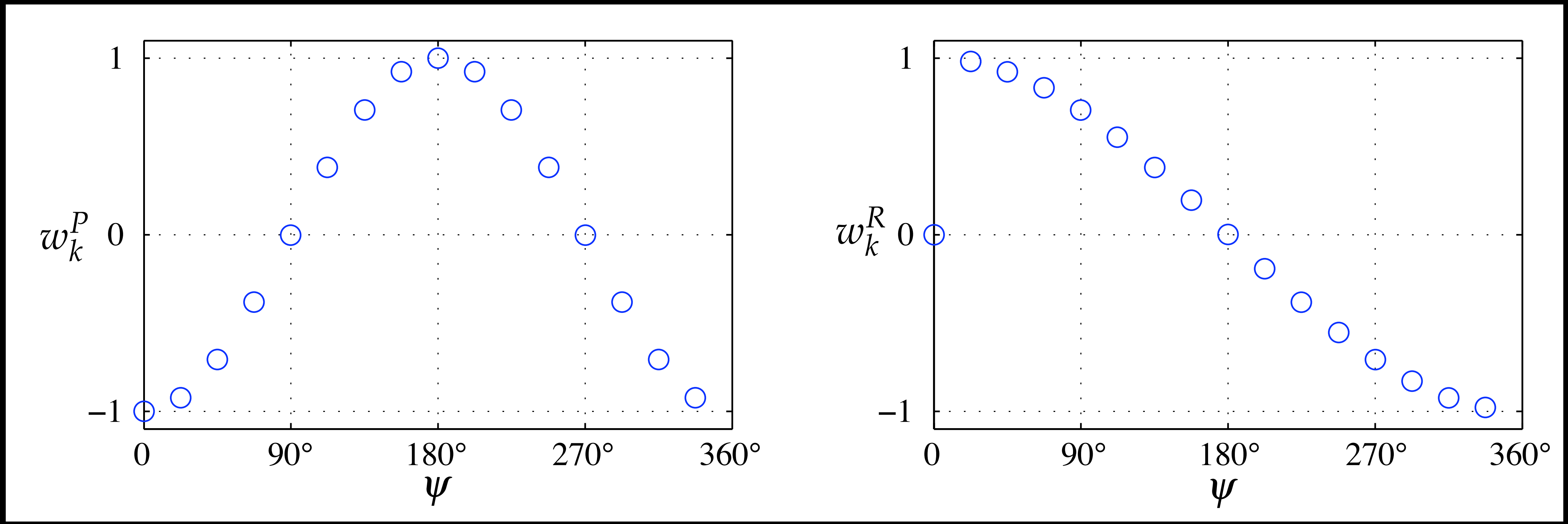
Weight distributions





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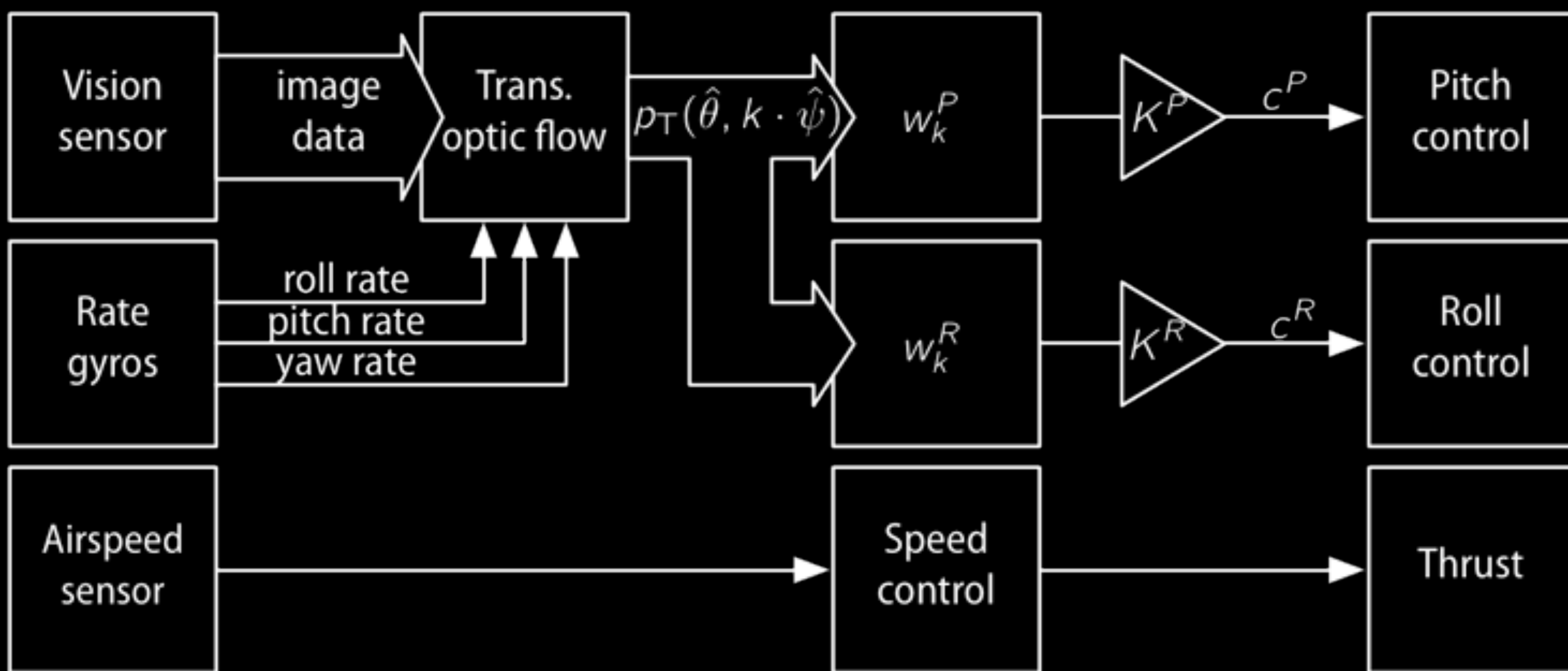
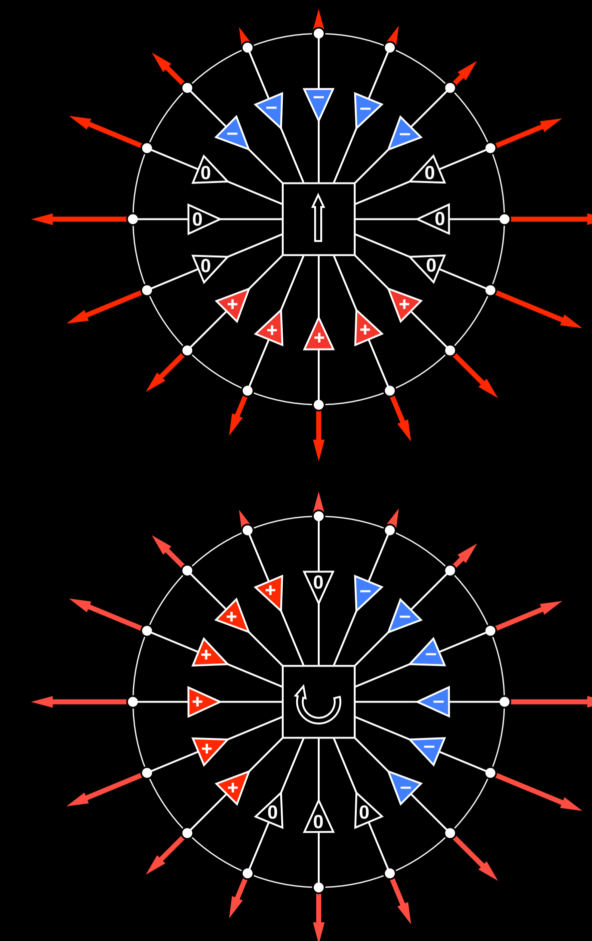
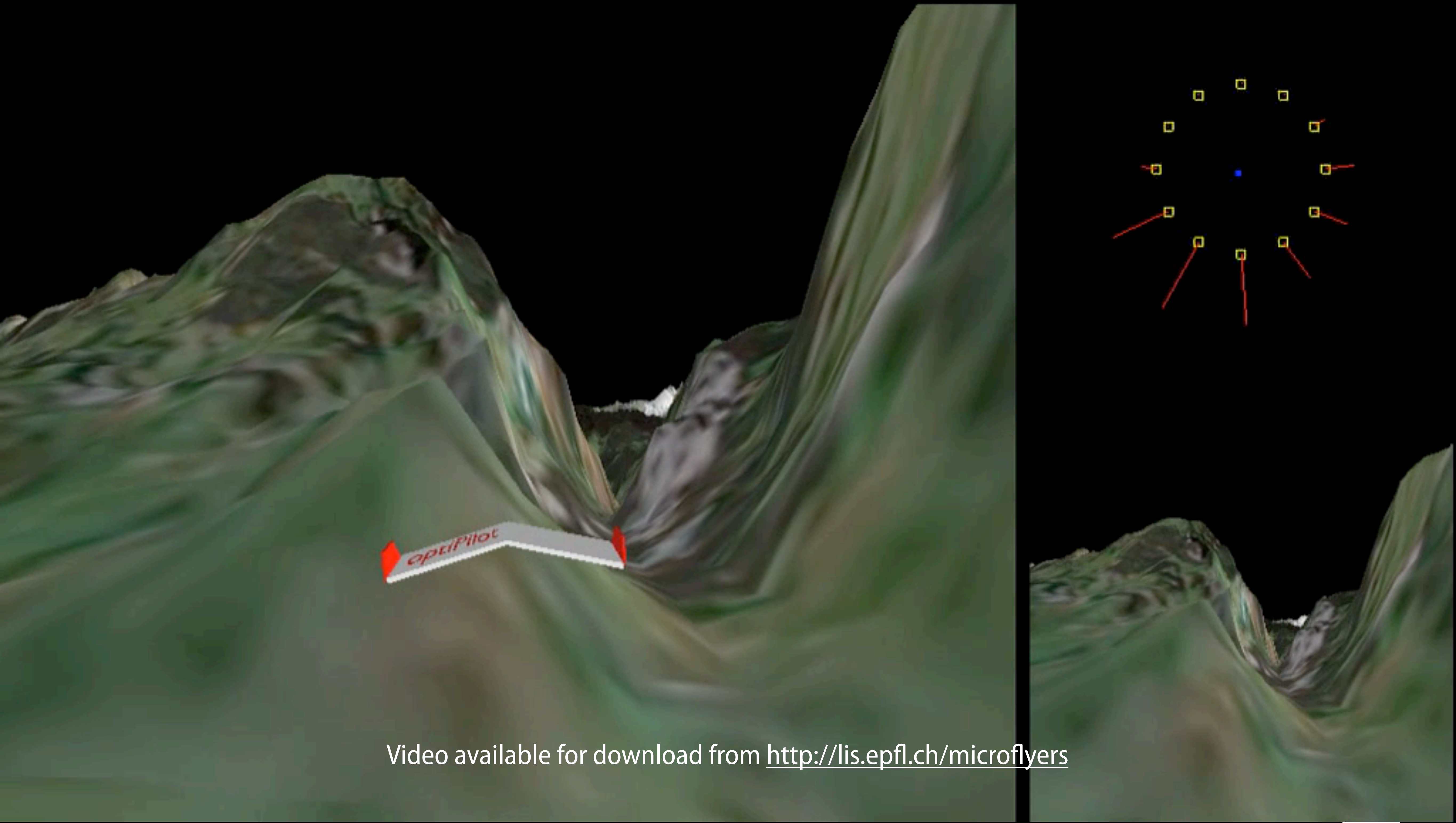
Control architecture





Beyeler, A., Zufferey, J.-C. and Floreano, D. Vision-based control of near-obstacle flight. ***Autonomous Robots***, 2009.

optiPilot à la montagne



Video available for download from http://lis.epfl.ch/microflyers

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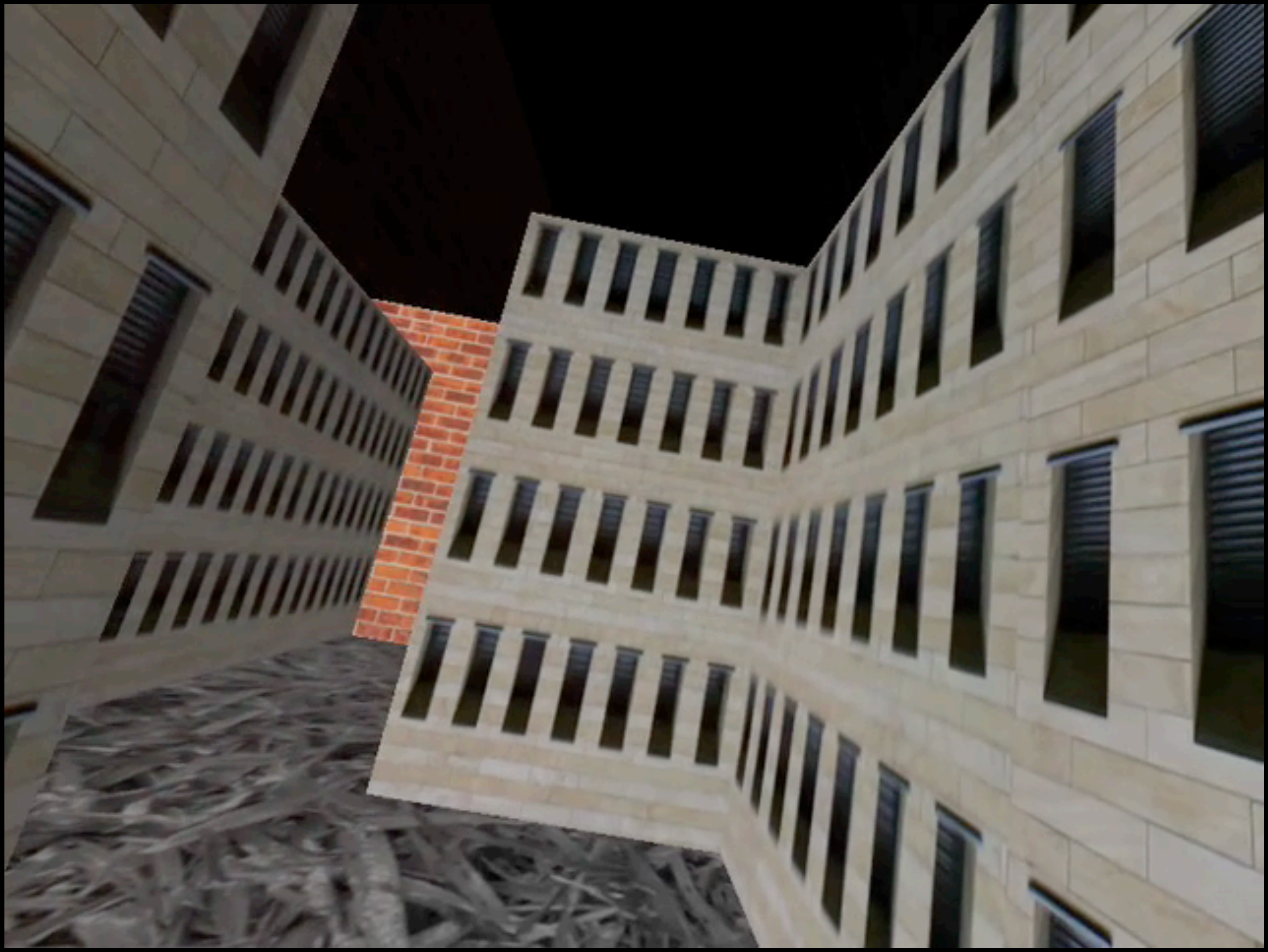
optiPilot à la ville



Video available for download from http://lis.epfl.ch/microflyers

optiPilot properties

Collision avoidance

Roll & pitch stabilization

Altitude control & terrain following

Take-off & landing

Coupling with higher-level control strategies (e.g. GPS navigation)

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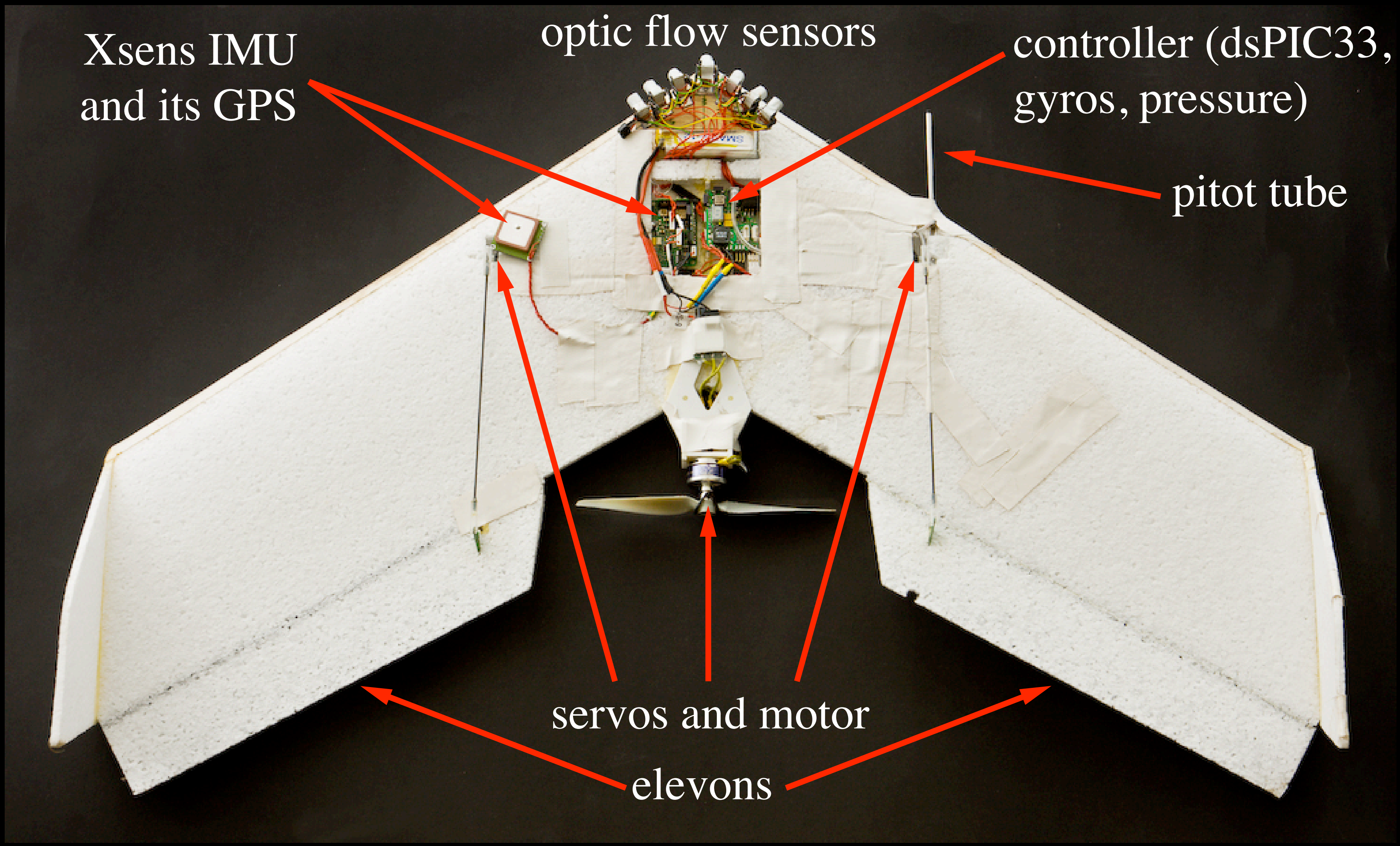
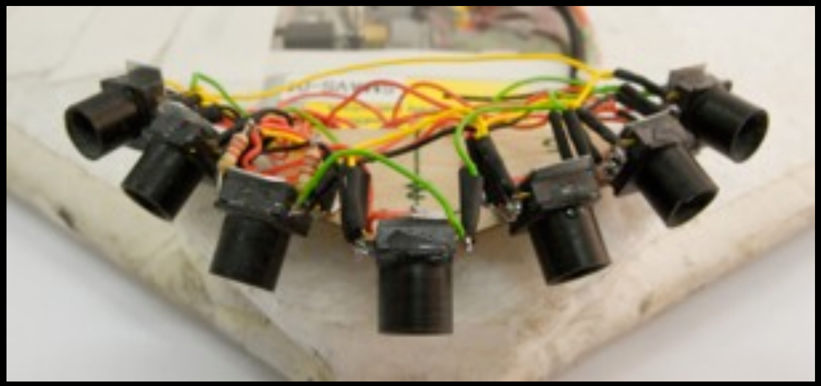
Test-bed





Avago ADNS5050

19x19 pixels

4500 fps

Modified lenses: 4.5-9 ° FOV

Beyeler, A., Zufferey, J.-C. and Floreano, D. Vision-based control of near-obstacle flight. ***Autonomous Robots***, 2009.

Terrain following

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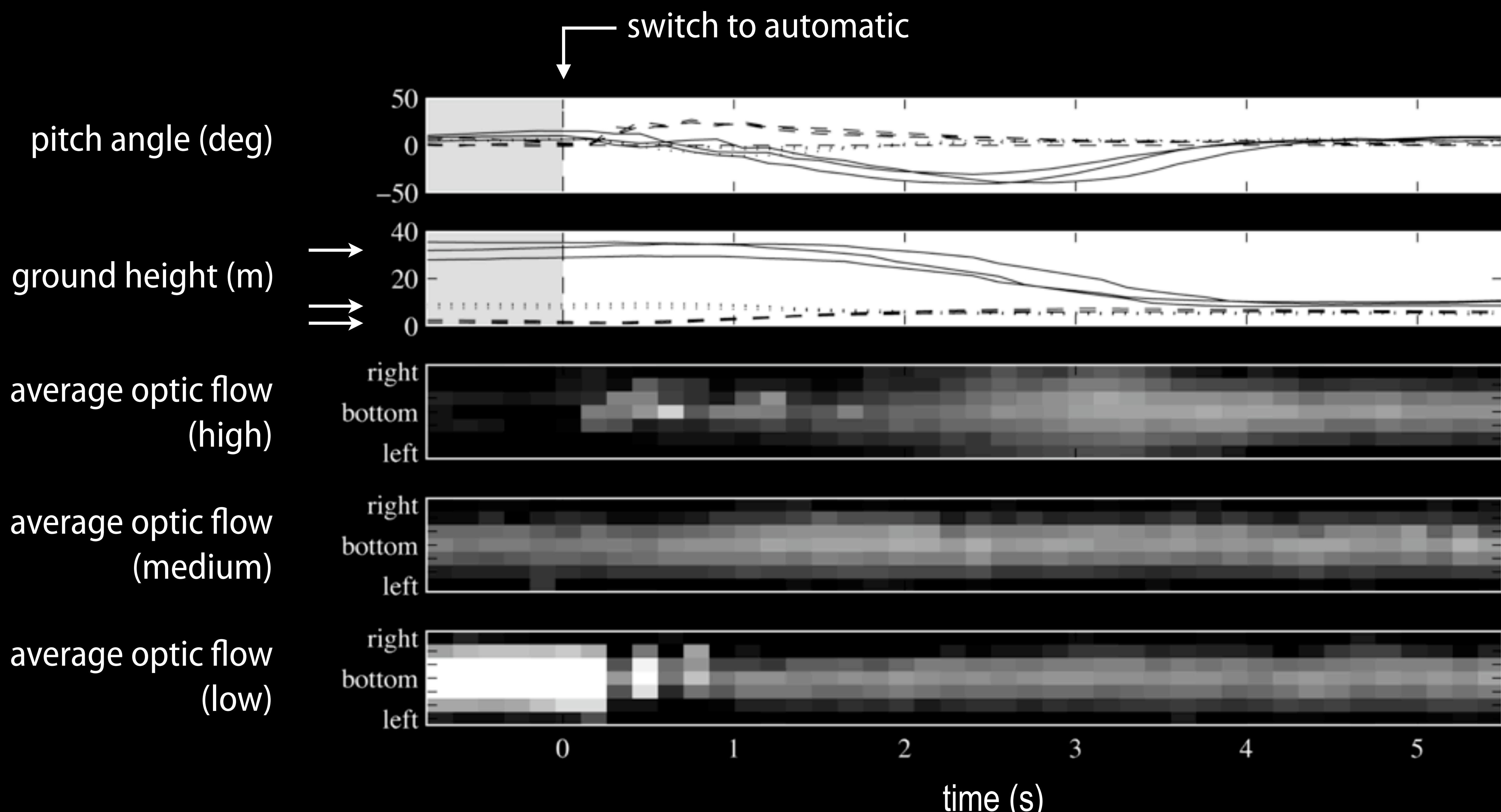
Altitude regulation



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Autonomous take-off

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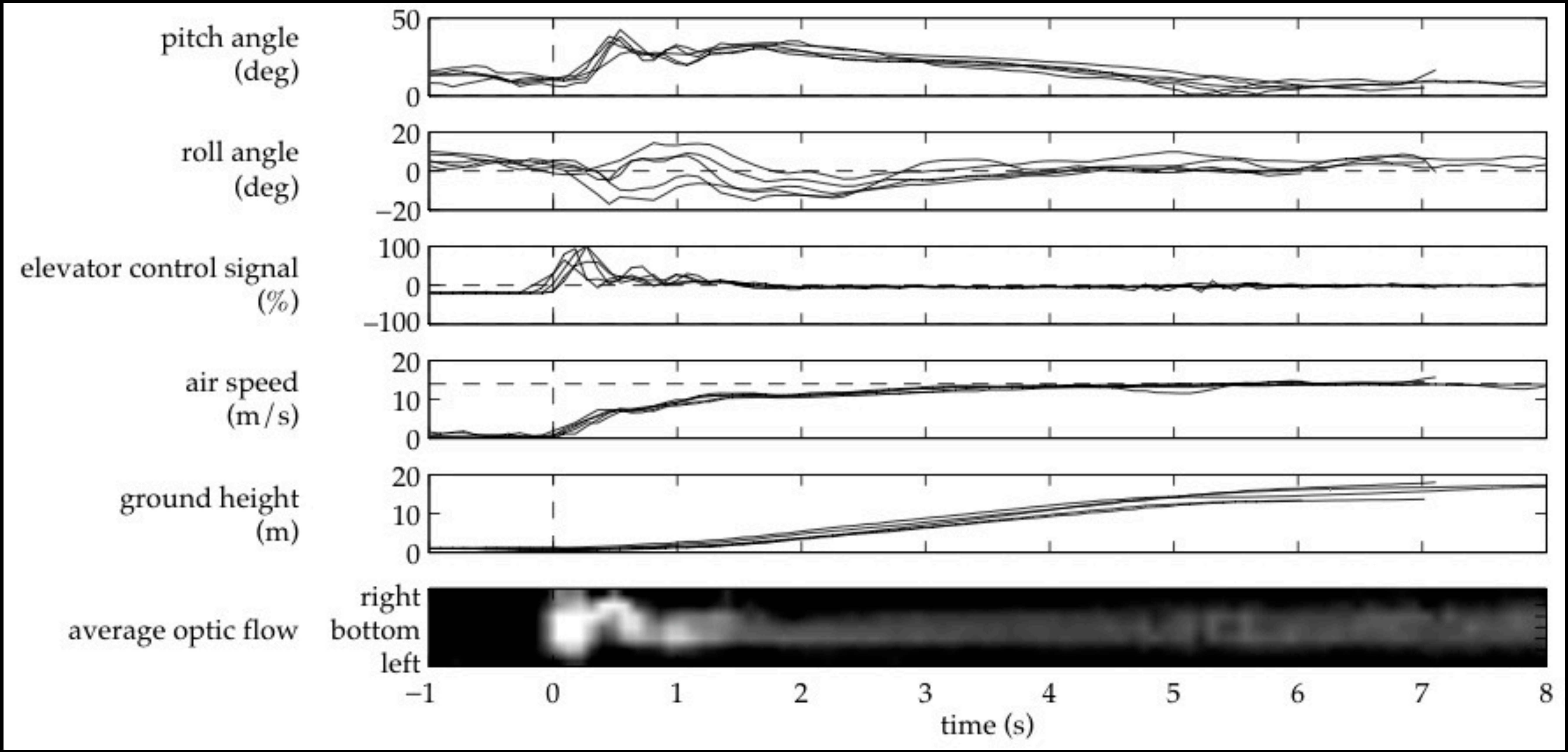
Take off



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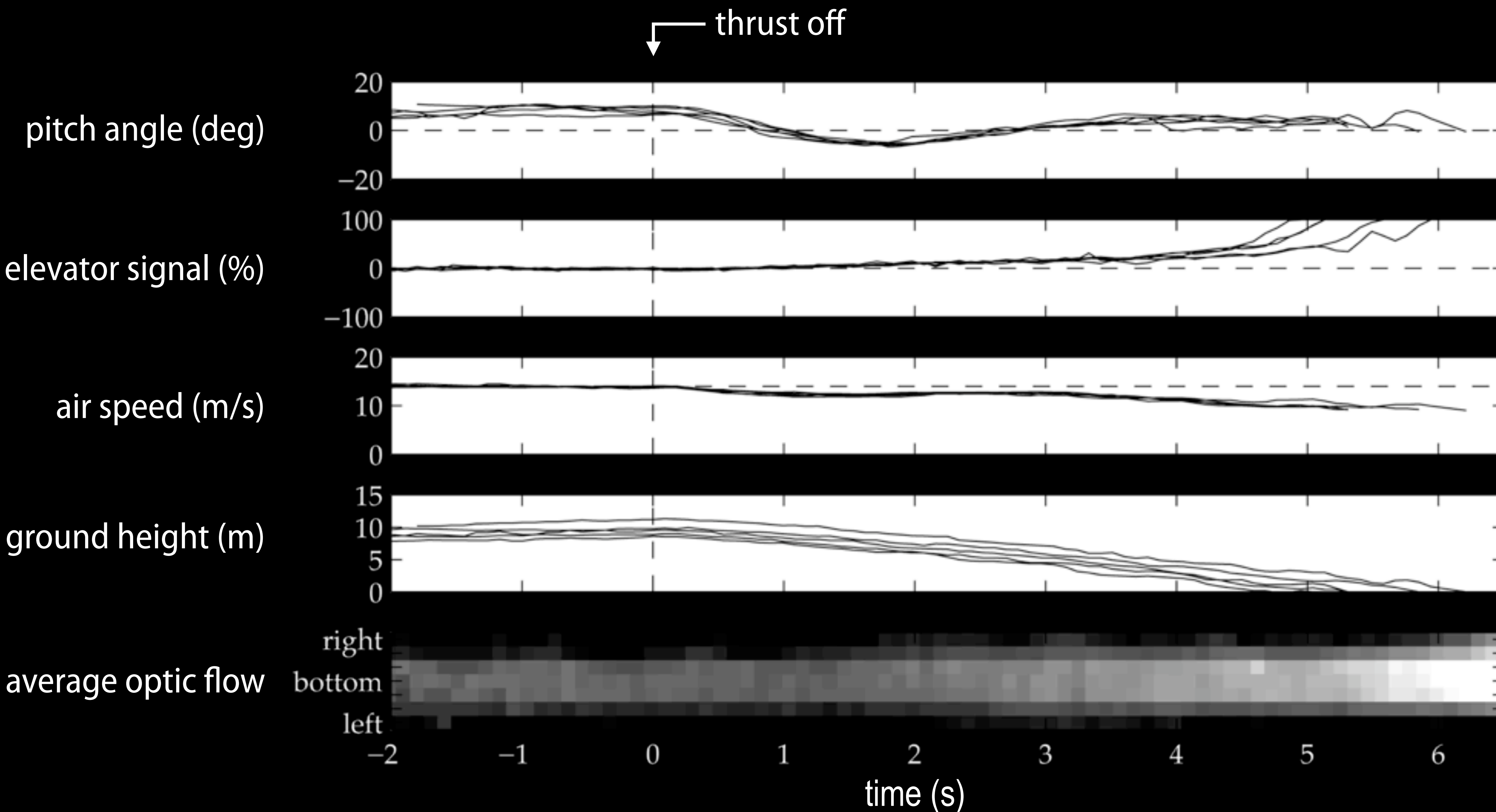
Autonomous landing

Landing



Beyeler, A., Zufferey, J.-C. and Floreano, D. OptiPilot: control of take-off and landing using optic flow.
Proceedings of the European Micro Air Vehicle conference and competition (EMAV), 2009.

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Rejection of perturbations

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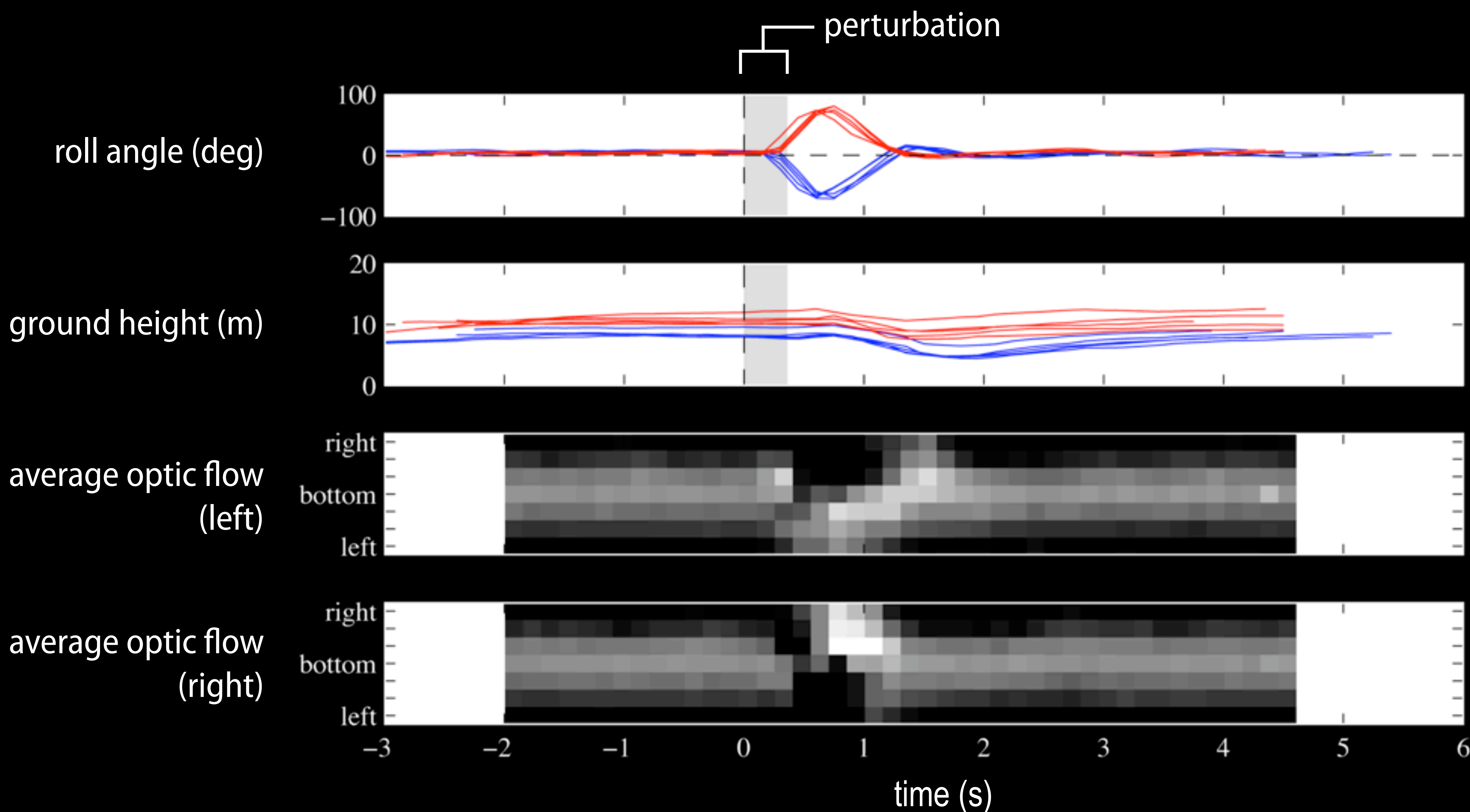
Roll regulation



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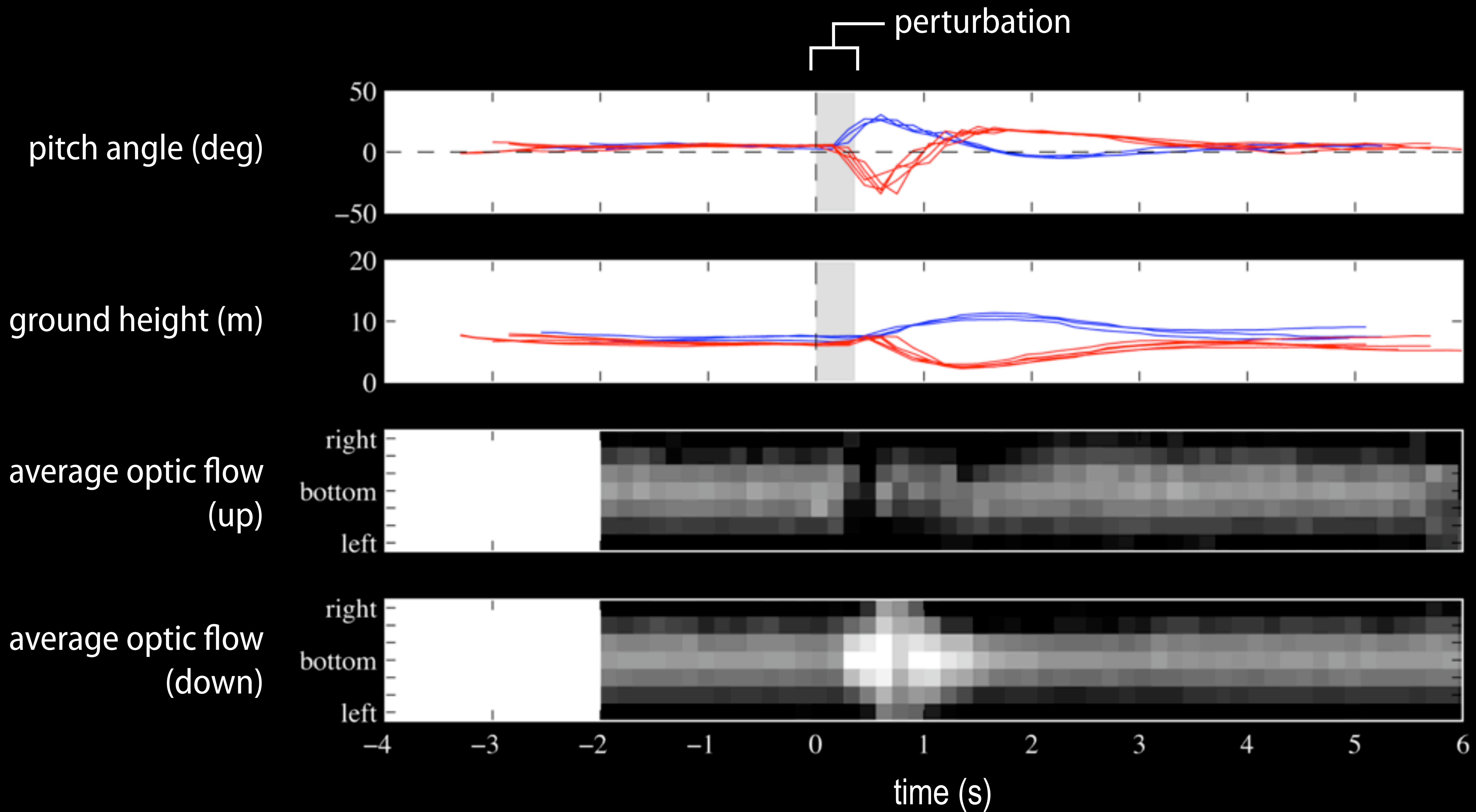
Pitch stabilisation



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Terrain avoidance = crash avoidance

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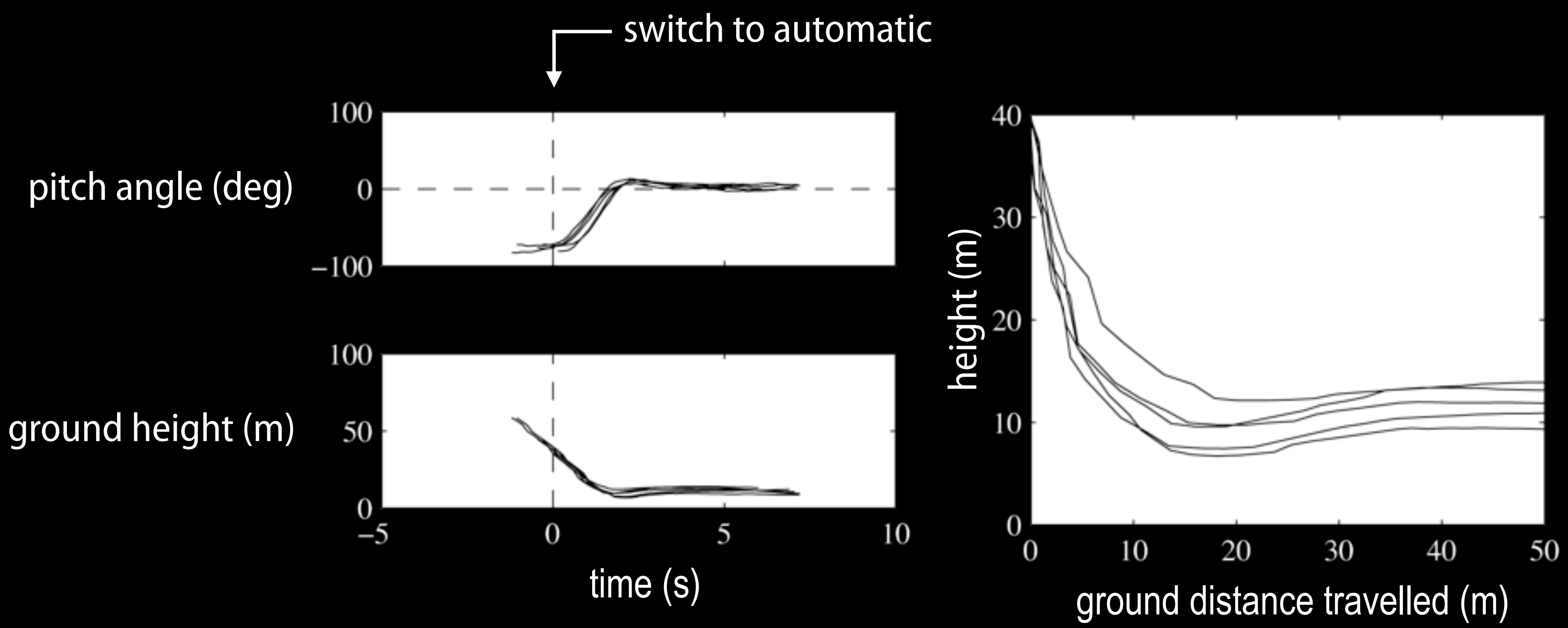
Recovery from vertical dive



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Obstacle avoidance

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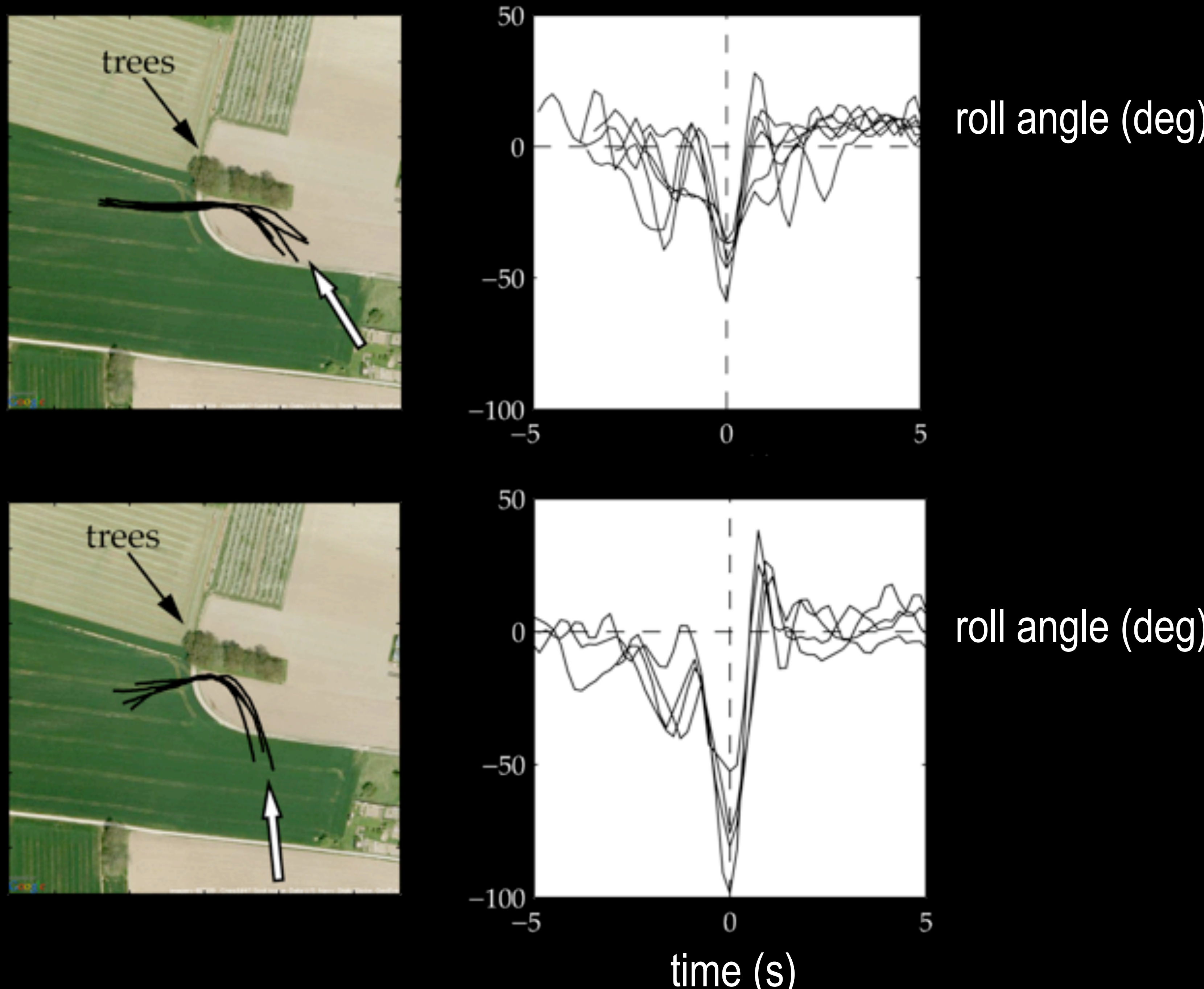
Obstacle avoidance



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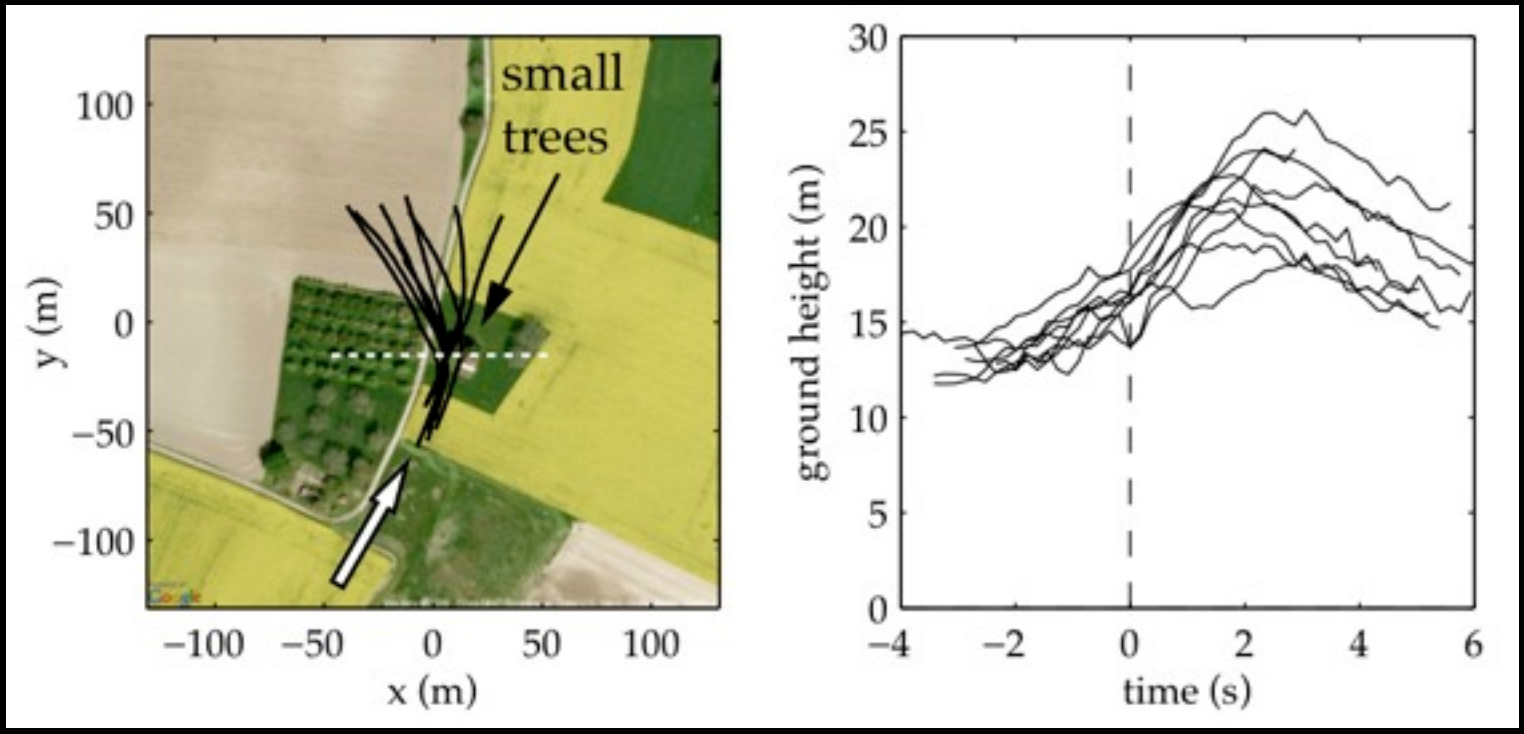
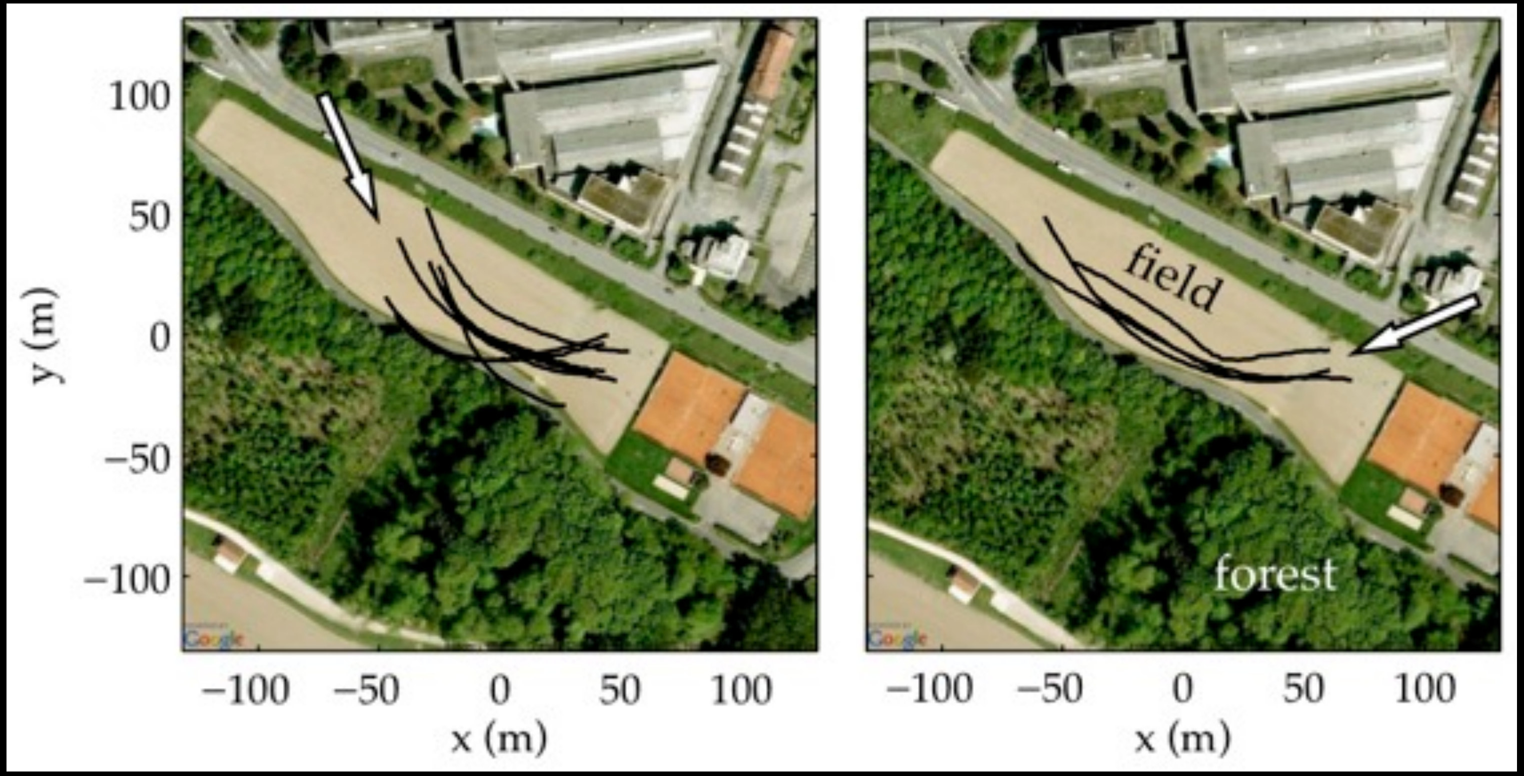
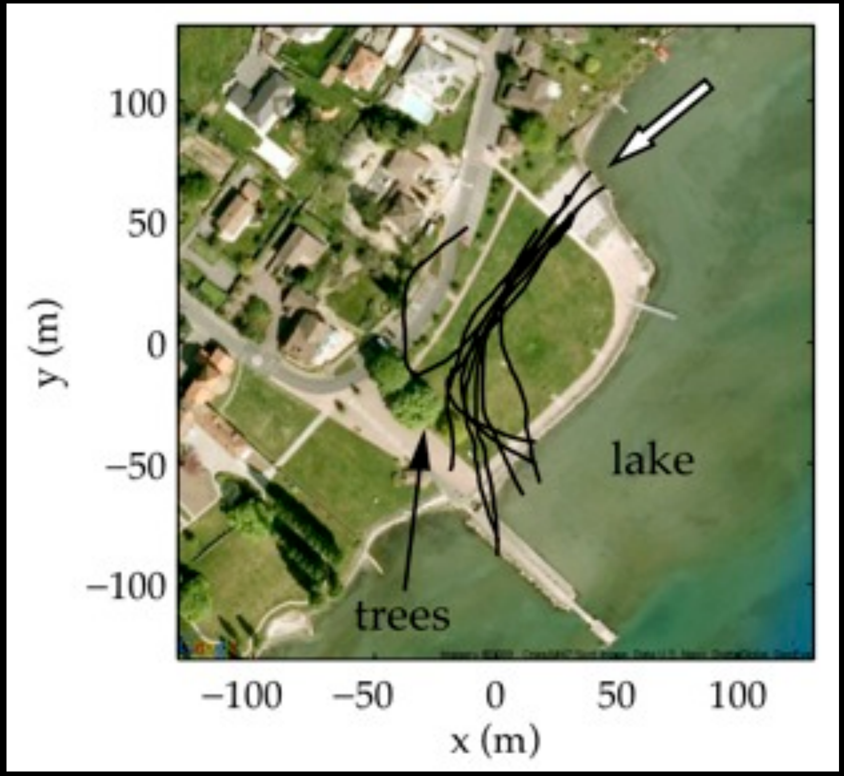
Obstacle avoidance







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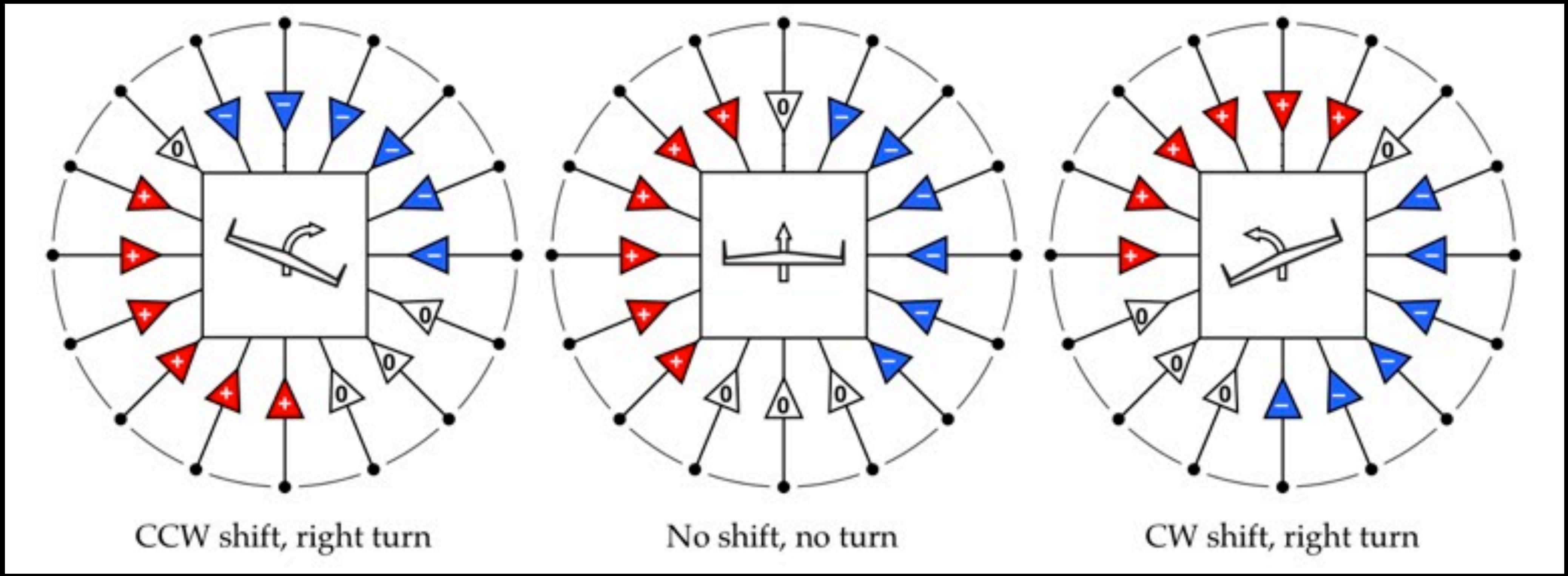
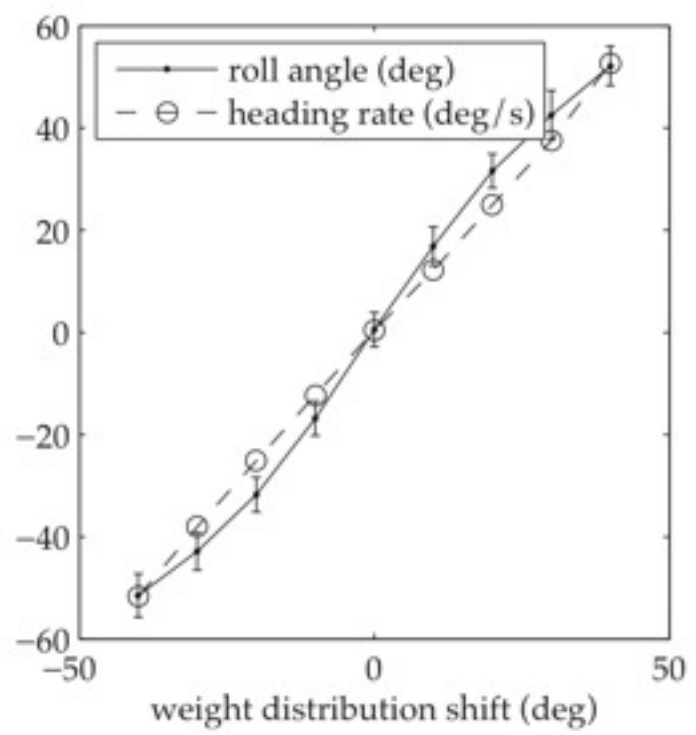
Steering control





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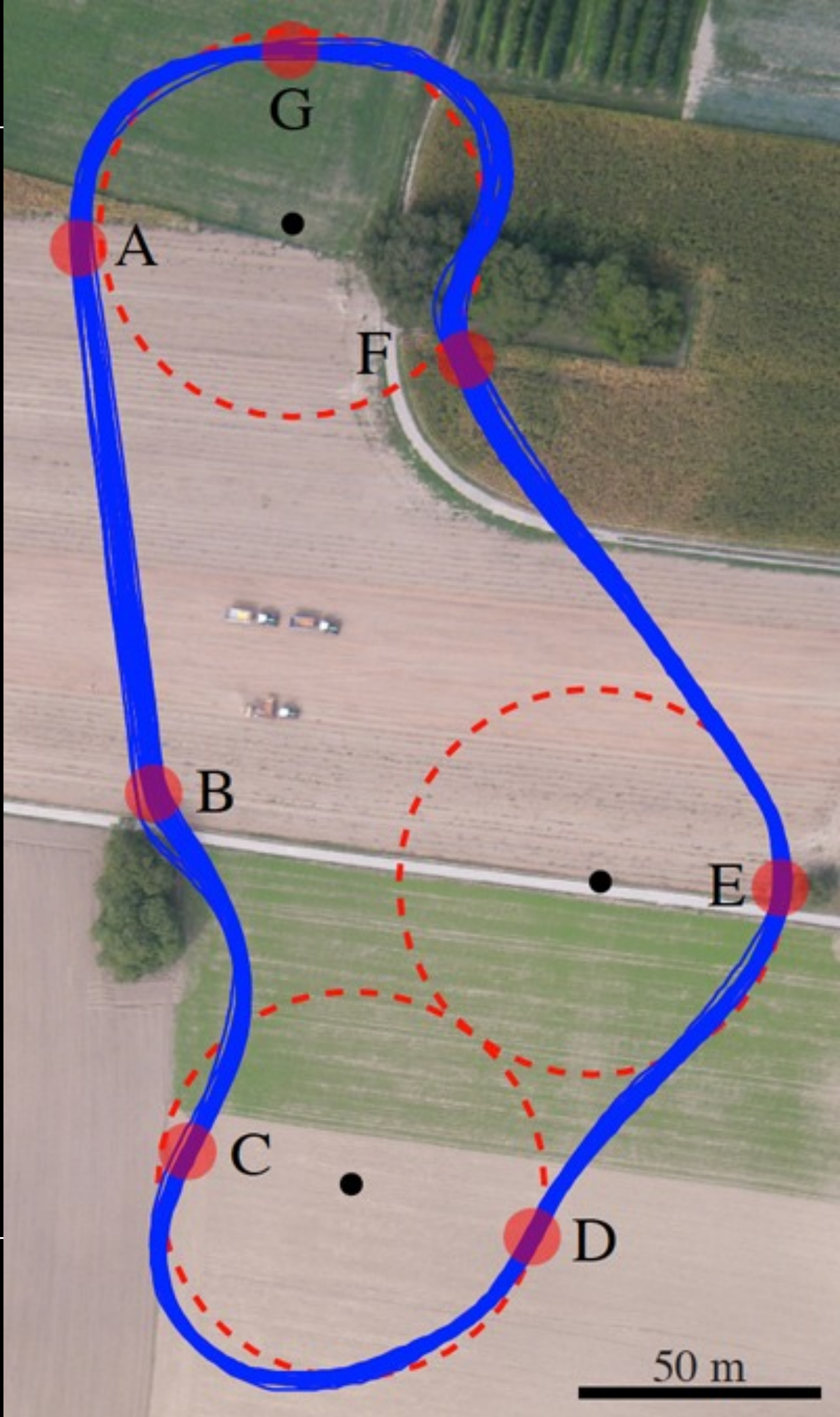
Coupling optiPilot with GPS

- Terrain following & collision avoidance = optiPilot
- Path following through optiPilot weight shifting

Beyeler, A., Zufferey, J.-C. and Floreano, D.
Autonomous flight at low altitude
with vision-based collision avoidance and GPS-based path following
Submitted to ICRA 2010



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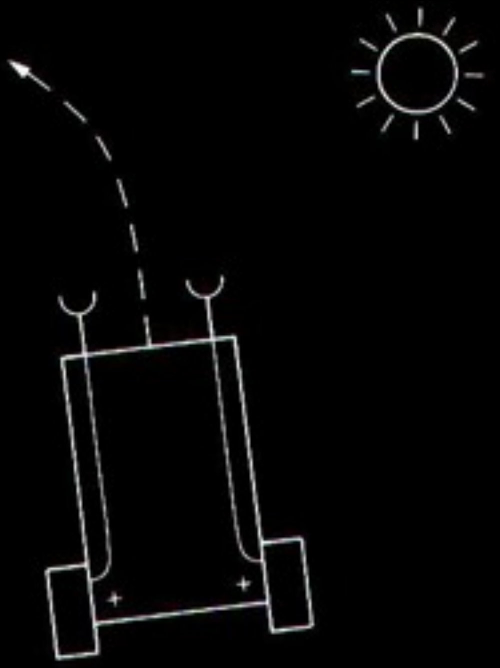
Conclusion

- Fully autonomous flight without GPS+IMU
- Complete flight control emerges from 3D collision avoidance
- Very parsimonious overall design (<1ms on dsPIC)



Braitenberg, 1984

- Future work:
  - » higher-resolution optic-flow detection
  - » test in man-made environments

Acknowledgements

Mandyam Srinivasan

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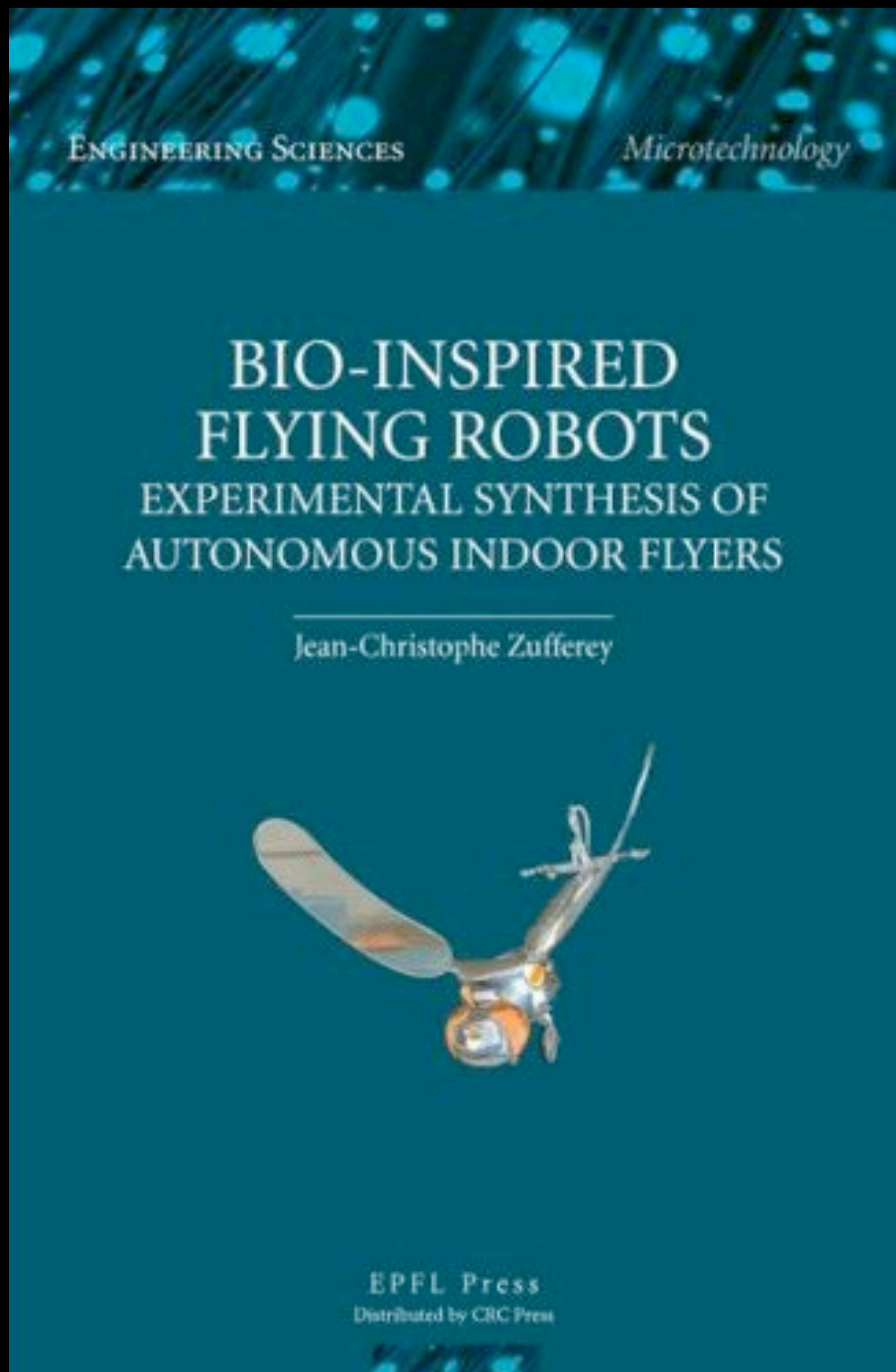

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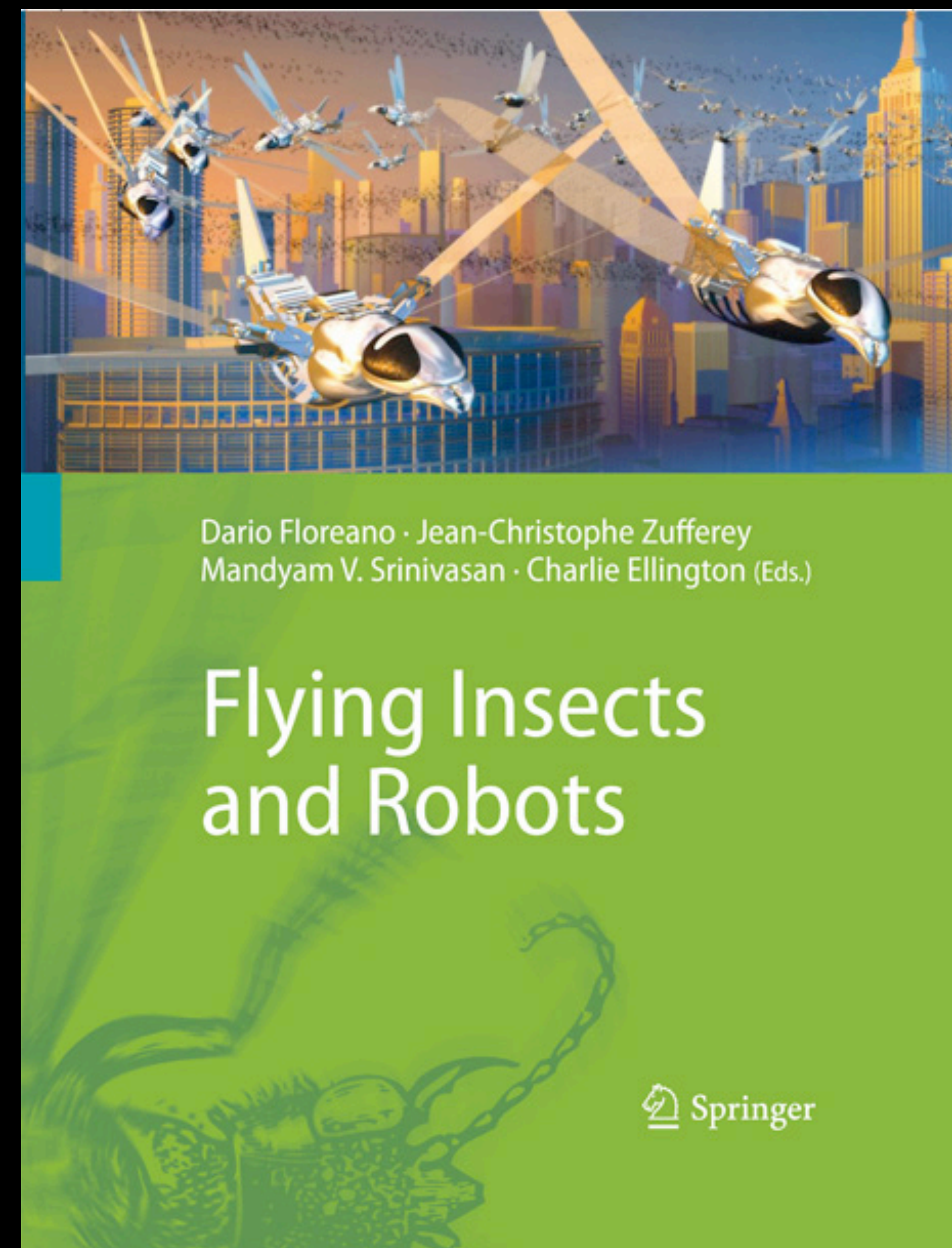

Dario Floreano · Jean-Christophe Zufferey
Mandyam V. Srinivasan · Charlie Ellington (Eds.)
Flying Insects and Robots
Springer

senseFly

- Fully autonomous (GPS+IMU+pressure)
- EPP foam => safe & crash resistant
- Max 500 g including 150 g payload
- Cross-platform software

www.sensefly.com