Laboratory of Intelligent Systems

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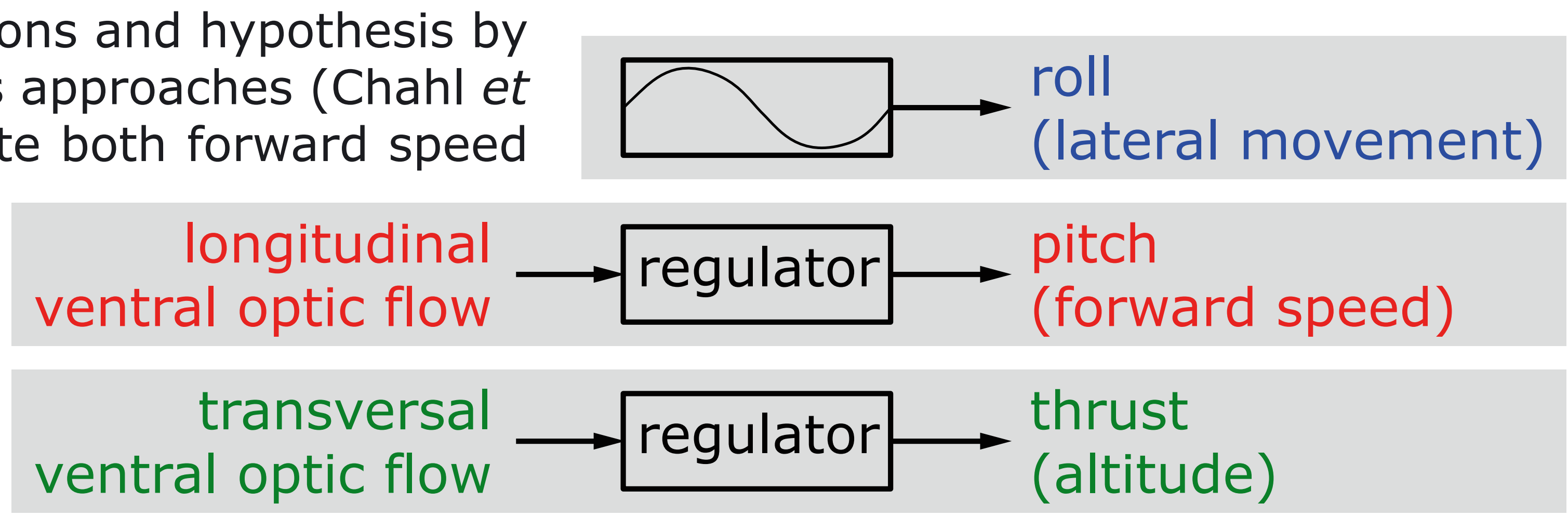
Optic-flow-based Altitude and Forward Speed Regulation using Stereotypical Lateral Movements

We propose a novel **optic-flow-based flight control strategy**, inspired by recent observations and hypothesis by Baird (unpublished), to regulate independently **forward speed** and **altitude**. Unlike previous approaches (Chahl *et al*, 2004; Franceschini *et al*, 2007), where longitudinal ventral optic flow was used to regulate both forward speed and altitude, we suggest to use **transversal ventral optic flow** generated by a **stereotyped lateral oscillation** to regulate altitude. Longitudinal ventral optic flow is still used to regulate forward speed. The main advantage of this strategy is to allow any combination of forward speed and altitude, which is not possible by using exclusively longitudinal ventral optic flow.

In this work, we propose a controller that implements this strategy and present the results of our initial simulations.



Agent dynamics and sensor model

The dynamics of our simulated agent is similar to that of **helicopters and insects** (Wagner, 1986; Deng *et al*, 2006)

- It can act on each of its 3 **rotational degrees of freedom** by 3 independent moments.
- It can act on the **amplitude of thrust**, but the direction is fixed with respect to the body.
- It is affected by gravity and air drag.

We consider **longitudinal and transversal ventral optic flow perceived exactly below the agent** (i.e. perpendicular to the ground) as the only sensory modality. In general, this requires knowledge of the angular position of the agent, but can be implemented by assuming a flat ground and finding the highest optic flow value in the ventral field of view.

Actuator force and torque

$$\hat{\mathbf{F}}_A(t) = i_T(t)\cdot\hat{\mathbf{F}}_{A0} = i_T(t)\begin{pmatrix}\hat{F}^x_{A0}\\ \hat{F}^y_{A0}\\ \hat{F}^z_{A0}\end{pmatrix} \qquad \hat{\mathbf{M}}_A(t) = \begin{pmatrix} i_\Phi(t)\cdot\hat{M}^x_{A0}\\ i_\Theta(t)\cdot\hat{M}^y_{A0}\\ i_\Psi(t)\cdot\hat{M}^z_{A0}\end{pmatrix}$$

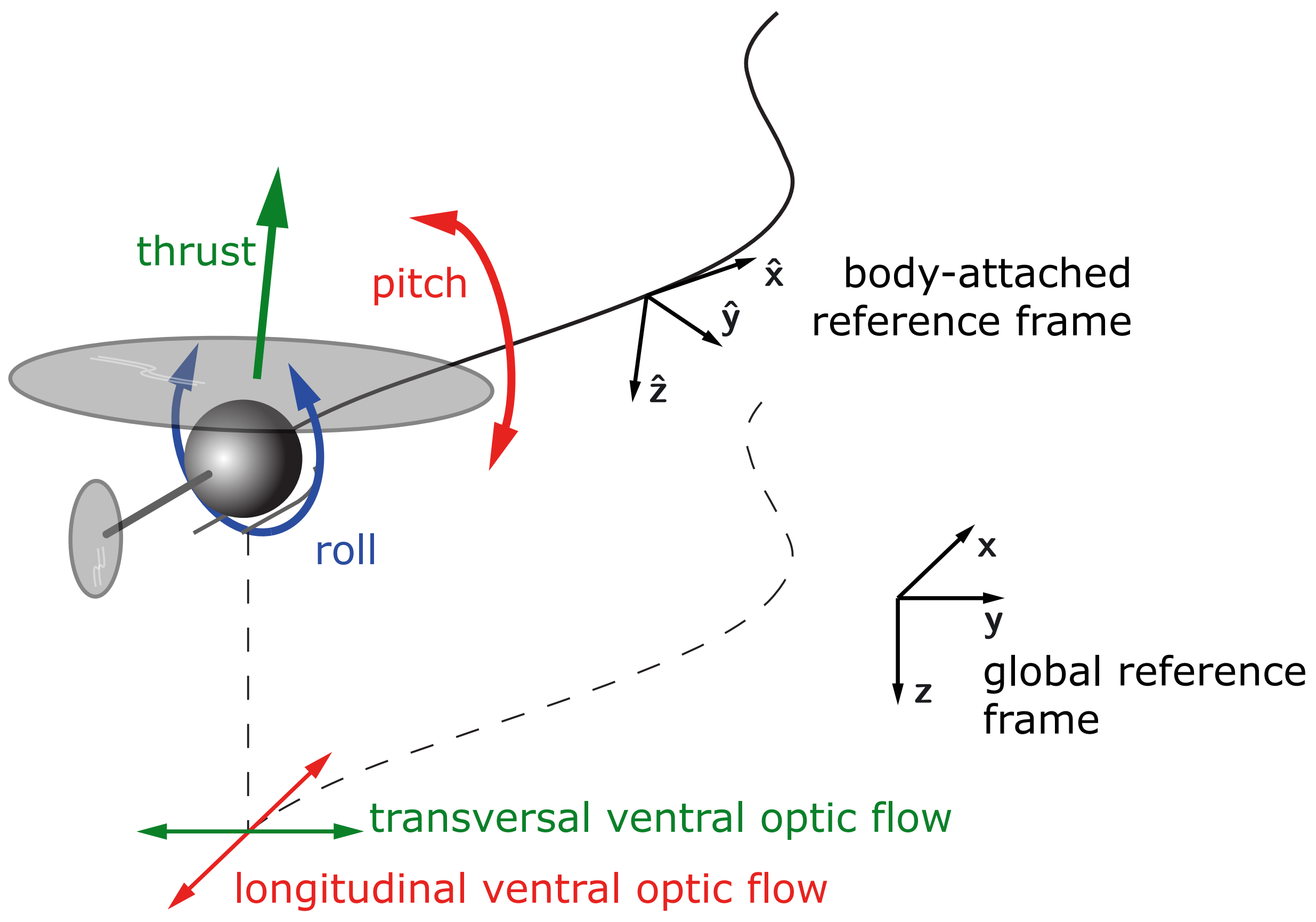
Gravity and air drag

$$\mathbf{F}_G = m\cdot\begin{pmatrix}0\\0\\g\end{pmatrix} \qquad \mathbf{F}_D(t) = -\frac{1}{2}\rho C A \mathbf{v}(t)^2\cdot\frac{\mathbf{v}(t)}{\|\mathbf{v}(t)\|}$$

$$\mathbf{M}_D(t) = -\frac{1}{2}\rho C_r \mathbf{w}(t)^2\cdot\frac{\mathbf{w}(t)}{\|\mathbf{w}(t)\|}$$

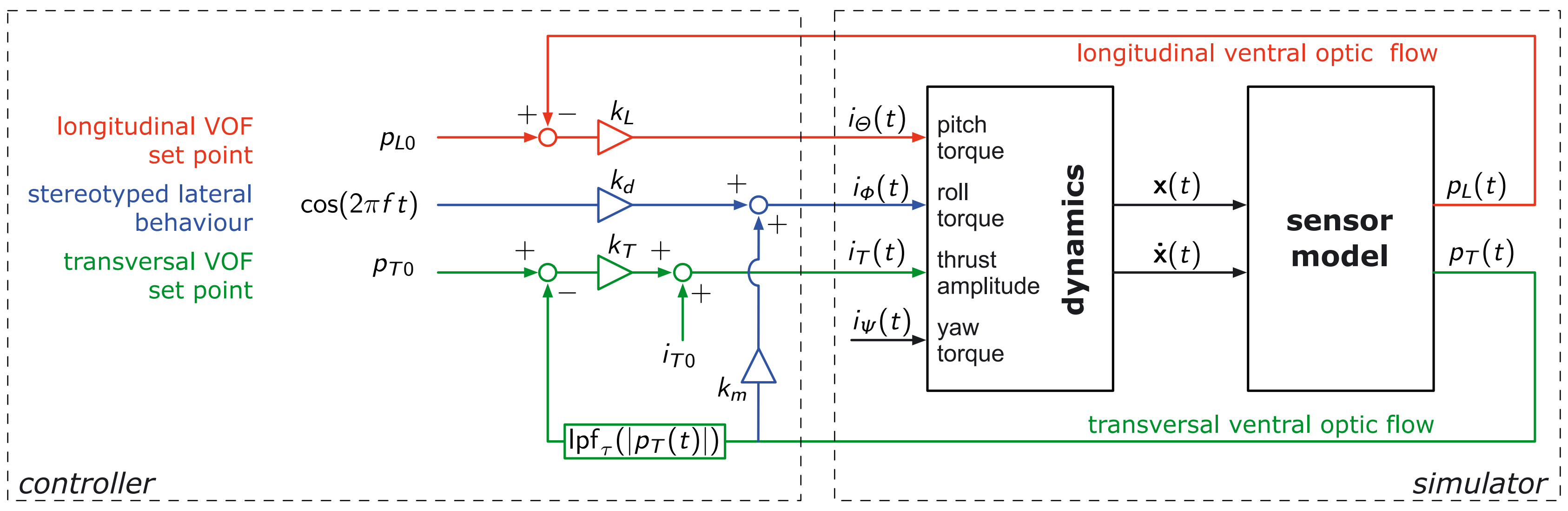
Dynamical equations

$$\begin{aligned}\mathbf{F}_A(t)+\mathbf{F}_G+\mathbf{F}_D(t) &= m\cdot\mathbf{a}(t)\\ \mathbf{M}_A(t)+\mathbf{M}_D(t) &= I\cdot\dot{\mathbf{w}}(t)\end{aligned}$$



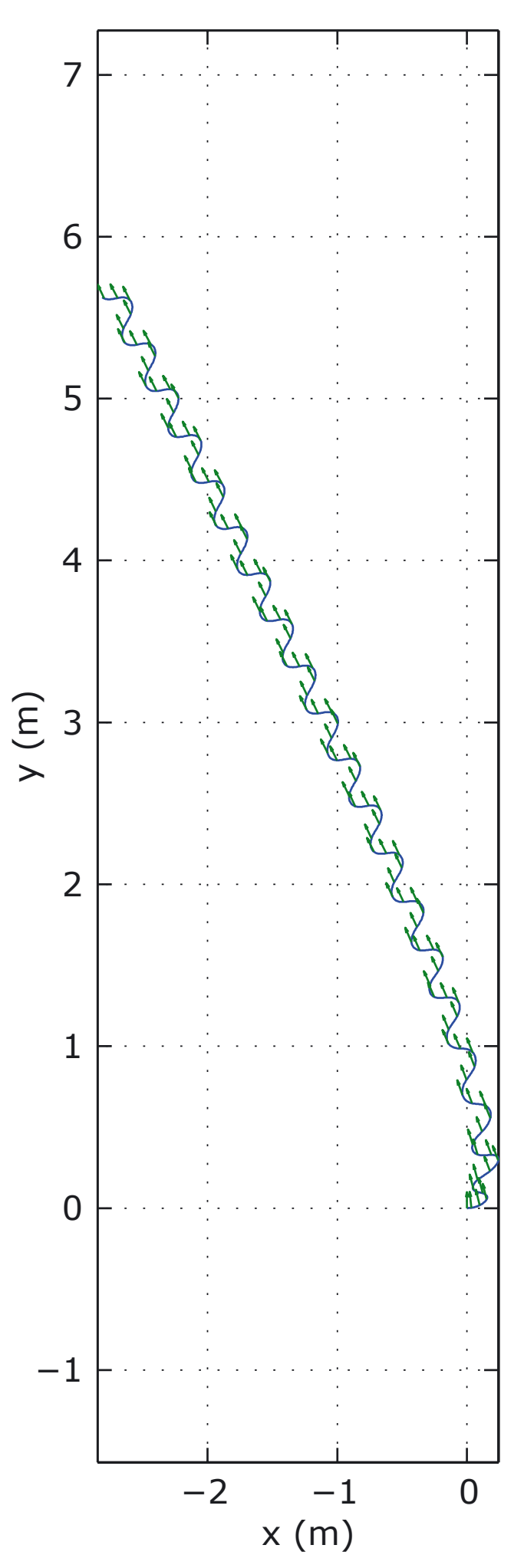
Controller

- The **roll torque** is controlled using an open-loop oscillatory signal modulated by the transversal ventral optic flow signal in order to stabilise average roll angle.
- The **pitch torque** is controlled by a proportional regulator to hold the longitudinal ventral optic flow constant. This is how forward flight speed is regulated.
- The **yaw torque** is set to zero at all times (heading control is not implemented is this study).
- The **thrust amplitude** is controlled by a proportional regulator (with an *a priori* term) to hold the absolute value of transversal ventral optic flow constant. This is how altitude is regulated.

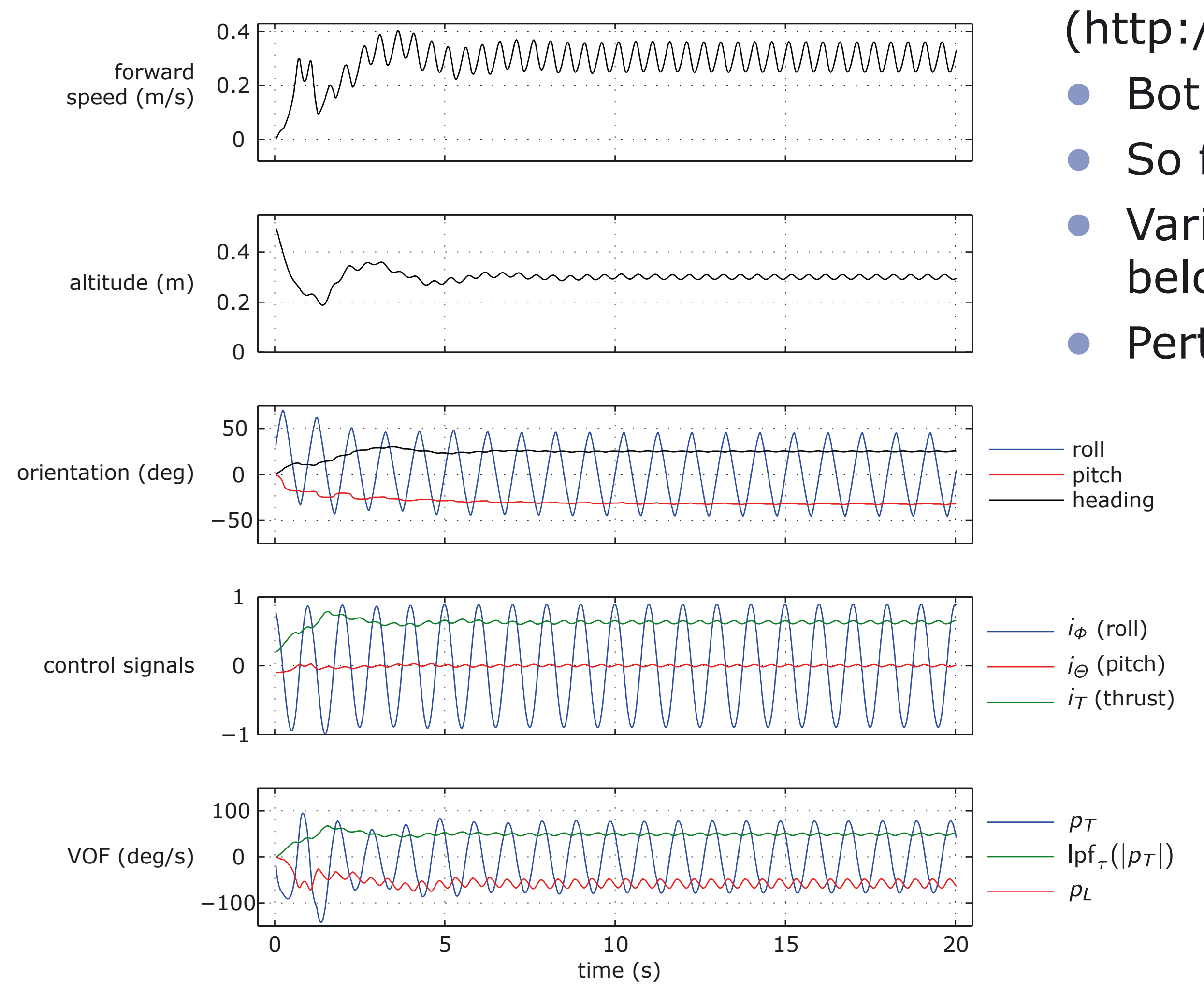


Results

Trajectory



Evolution over time



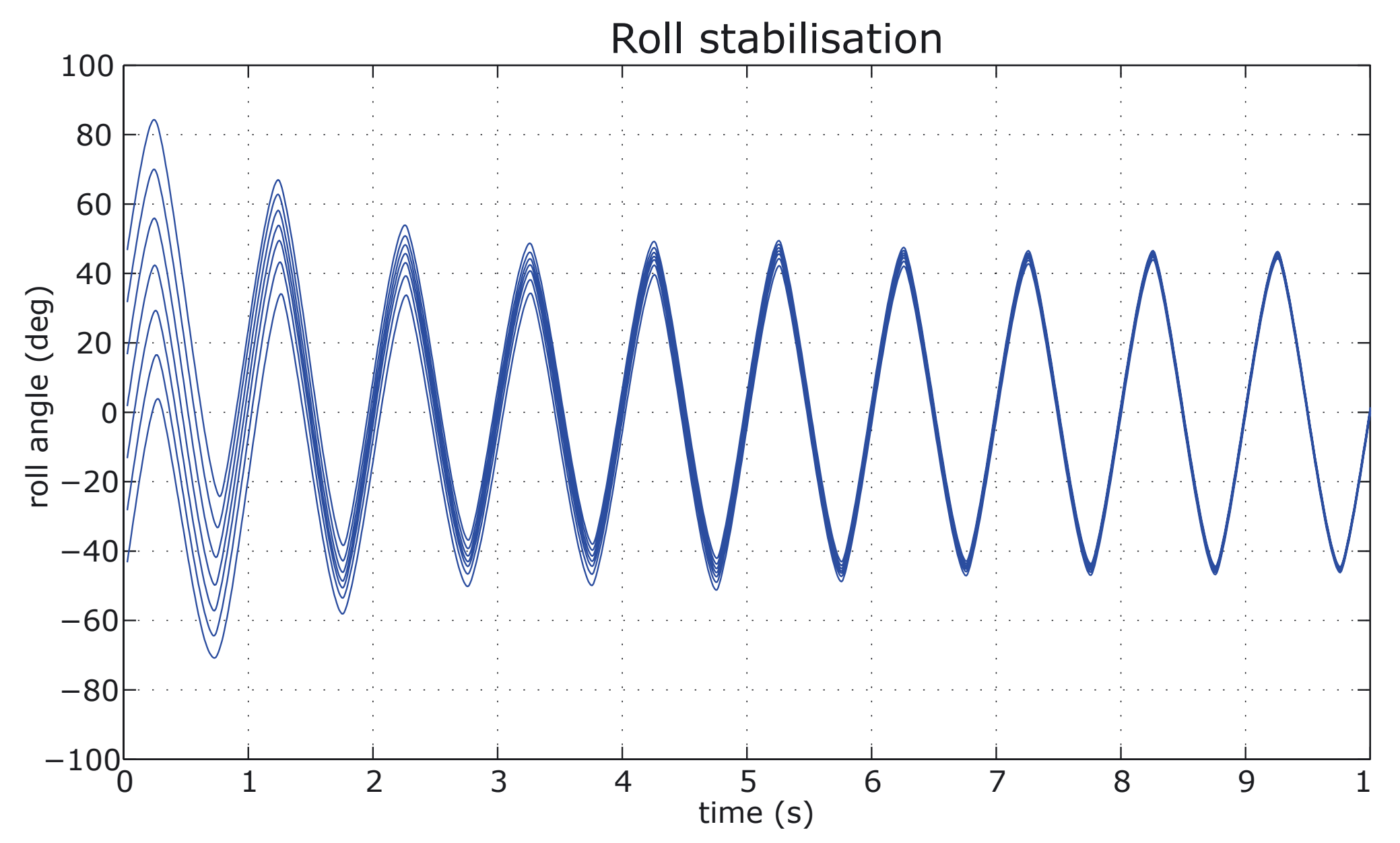
In order to assess our control strategy, we ran the controller presented above in a simulation setup (http://lis.epfl.ch/enlil) where the agent dynamics and sensor model was implemented.

- Both **altitude** and **forward speed** stabilise to a **constant value**.
- So far, **heading** is not regulated and may be affected by perturbations.
- Various sets of **optic flow set-points** lead to different forward speed and altitude (see table below).
- Perturbations on roll are rejected thanks to the modulation of the lateral behaviour.

Influence of set-points on forward speed and altitude

p_{L0} / p_{T0}	**0.0** (rad/s)	**0.5** (rad/s)	**1.0** (rad/s)	
0.4 (rad/s)	0.00	0.30	0.35	**fwd sp.** (m/s)
	1.20	0.61	0.35	**alt.** (m)
0.6 (rad/s)	0.00	0.25	0.32	**fwd sp.** (m/s)
	0.68	0.51	0.32	**alt.** (m)
0.8 (rad/s)	0.00	0.20	0.29	**fwd sp.** (m/s)
	0.48	0.41	0.30	**alt.** (m)

Roll stabilisation



Discussion

This control strategy allows to control a helicopter- or insect-like agent with any combination of forward speed and altitude. Moreover, thanks to a modulation of the open-loop oscillatory drive of the roll behaviour, this strategy achieves roll stabilisation.

Interestingly, the final behaviour shares many similarities with honeybees – especially in terms of oscillating trajectories – as recently recorded by Baird (at Australian National University, unpublished). Therefore, this result paves the way toward both novel approaches in flying robot control and formulation of biological hypotheses about the mechanisms underlying insect flight.

Future work

- **Realistic optic flow** will be used, including detection of the peak amplitude in the ventral field of view.
- A **heading control mechanism** will be added to the controller.
- The current study assumes infinitely flat ground. More work is required to assess the performance on **uneven ground** or in presence of **ground obstacles**.
- Using a more precise **insect flight model** would allow to make comparison with tracking data of real insects and could potentially lead to **biological hypothesis**.

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Biologists have shown that navigation in flying insects is based primarily on optic flow cues [1, 2]. This strategy has inspired control mechanisms of several flying robots, in particular for forward speed regulation and altitude control [3-6].

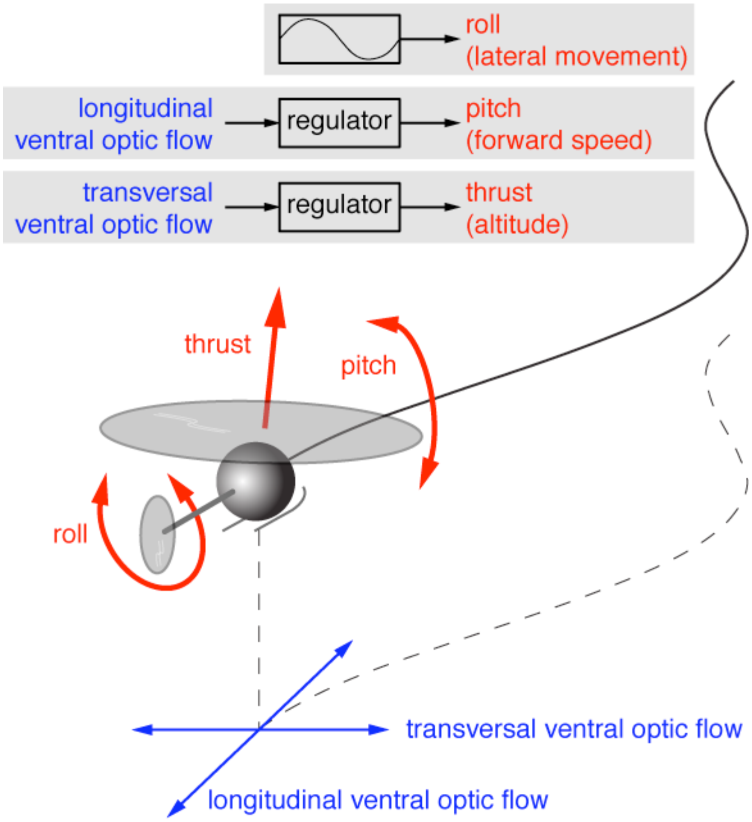

Figure 1. Illustration of the flight controller for the flying agent. Stereotyped roll control induces oscillatory lateral movements that generate transversal ventral optic flow, which is in turn used to control thrust (altitude regulation). Longitudinal ventral optic flow is used to control pitch (forward speed regulation). Note that the direction of thrust is fixed with respect to the body of the agent.

The flight control strategy thought to be used by insects and commonly implemented in robots is based on the longitudinal ventral optic flow (i.e. the component of optic flow perceived below the agent that is parallel to the general direction of flight, see figure 1) [5-7]. It has been shown that holding this component of optic flow constant allows sustained flight and ground obstacle avoidance [6]. However, this strategy does not allow independent regulation of altitude and forward flight speed. Since longitudinal optic flow cues are proportional to forward speed and inversely proportional to altitude, any perturbation (e.g. wind) on one component of flight will translate into a change in the other.

We propose here a novel flight control strategy (illustrated in figure 1) to cope with the ambiguity of altitude and forward speed regulation. This is achieved using a stereotyped lateral oscillation that generates transversal ventral optic flow (i.e. component of ventral optic flow perpendicular to the general direction of flight), which can be used to regulate altitude independently from forward speed. Specifically, the amplitude of *transversal* ventral optic flow is held constant by controlling thrust, to regulate altitude, while *longitudinal* ventral optic flow is maintained constant by controlling pitch, to regulate forward speed.

We assess this new control scheme using a simulated agent with dynamics similar to that of insects and helicopters [8, 9] and show that altitude and forward speed can effectively be regulated independently. Furthermore, by modulating the stereotypical lateral behaviour using transversal ventral optic flow, we show that roll perturbations can be rejected, effectively achieving roll stabilisation.

Interestingly, the final behaviour shares many similarities with honeybees – especially in term of oscillating trajectories – as recently recorded by Baird and Boeddeker (at the Australian National University, unpublished data). Therefore, this result paves the way toward both novel approaches in flying robot control and formulation of biological hypotheses about the mechanisms underlying insect flight.

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