המכון למדעי החיים
ע"ש אלכסנדר סילברמן
האוניברסיטה העברית בירושלים
The Alexander Silberman Institute of Life Sciences
The Hebrew University of Jerusalem

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM
ביה"ס להנדסה ולמדעי המחשב ע"ש רחל וסלים בנין
The Rachel and Selim Benin School of Computer Science and Engineering

CIDR
Center for Interdisciplinary Data Science Research

Deep Learning Approach to Flapping Wing Flight Control: Leveraging Reinforcement and Imitation Learning from Fruit Flies

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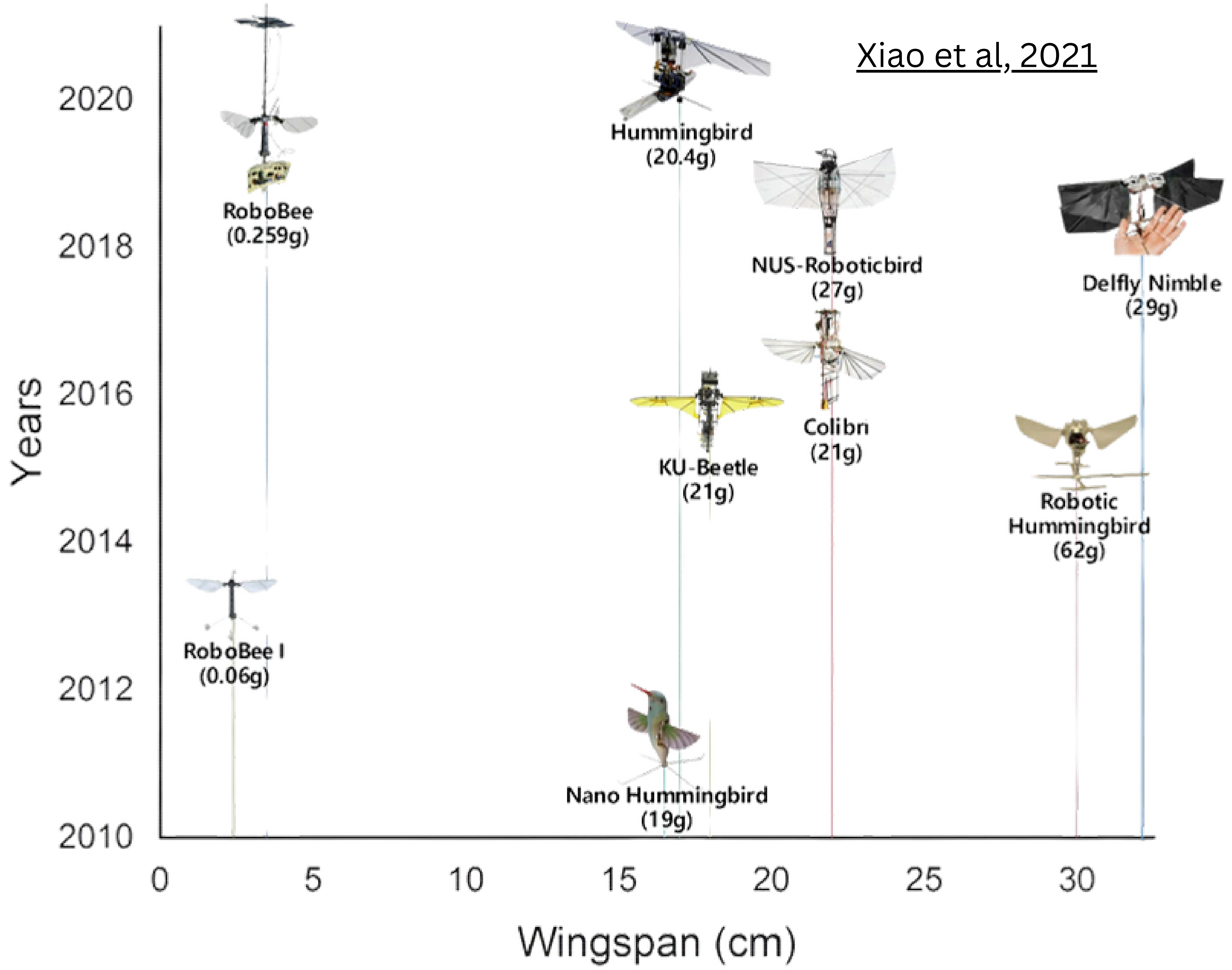
Under the supervision of

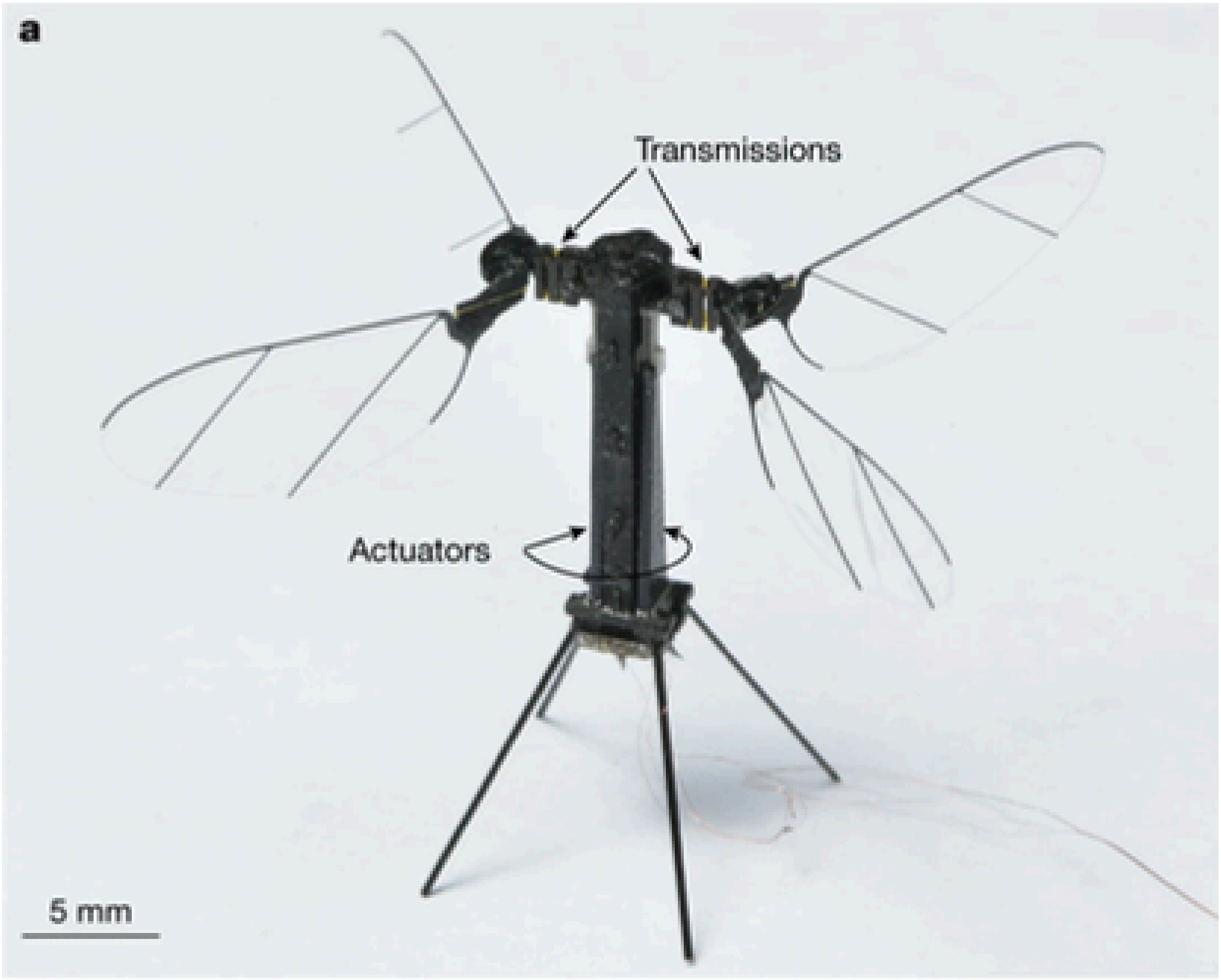
Prof. Tsevi Beatus

IAAC, April 2025

Introduction - Flapping Wing MAVs Are Coming!

- Inefficient aerodynamic setup of current MAV
- Improvements in robotics and avionics
- **We need good controllers**

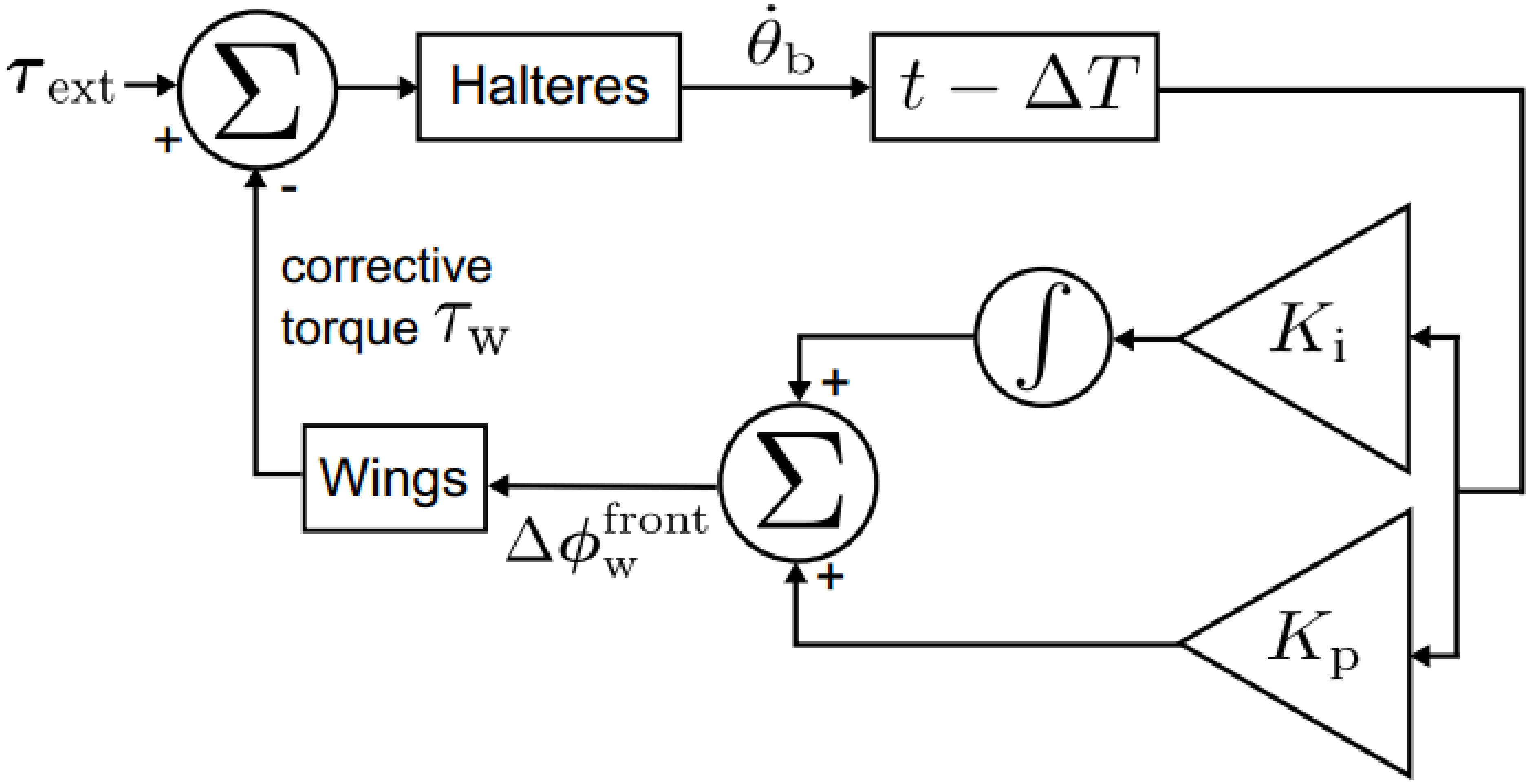




Robobee X-Wing (Jafferis et al,2019)

Introduction - Biomimicry can help?

- Current models of flies are PID based
- Address only angular control but are highly coupled with velocities
- Hard to find actual parameters



Beatus 2015, Whithead & Beatus 2015

Introduction - What is our goal?

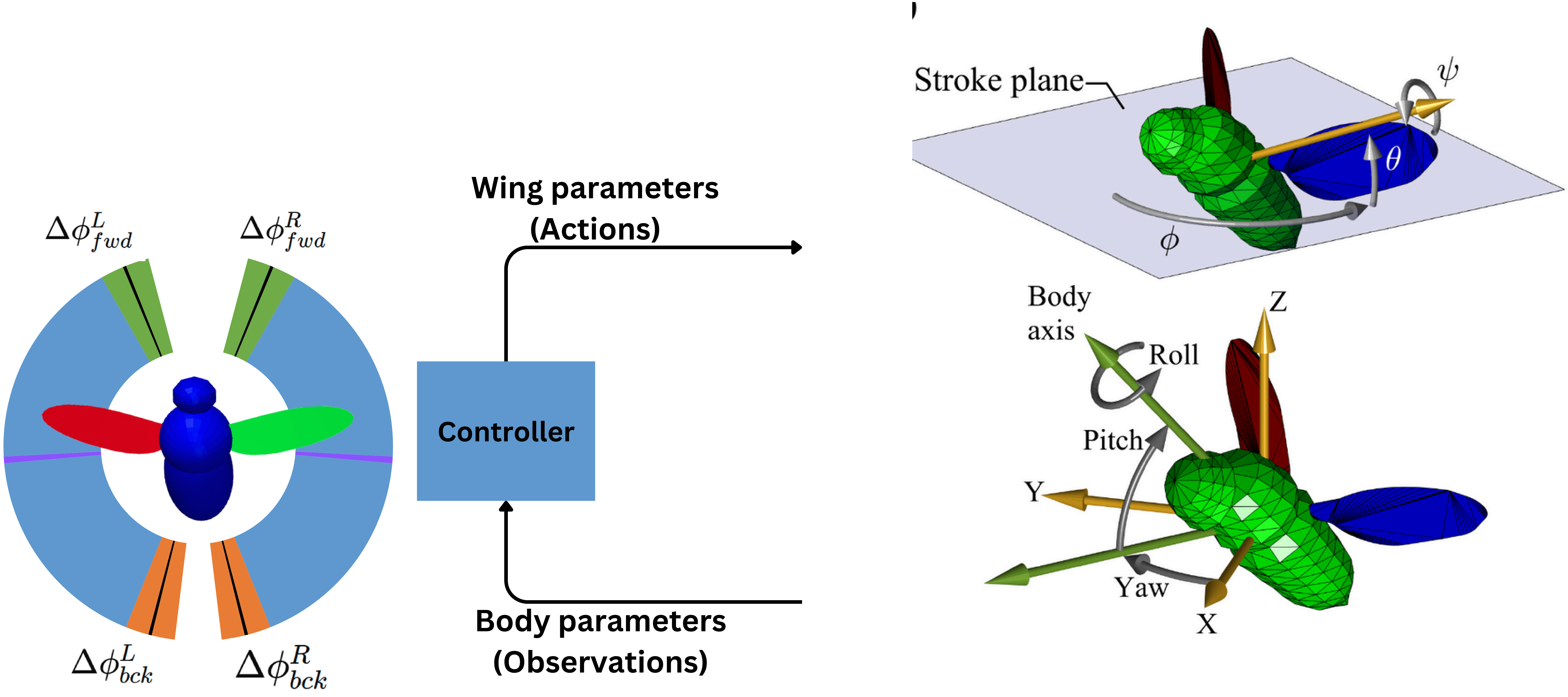
- Stable controller for all axes combined
- Robust
- Adaptive
- Efficient

What do we need?

- Simulation
- Data acquisition system
- Algorithm

Simulation

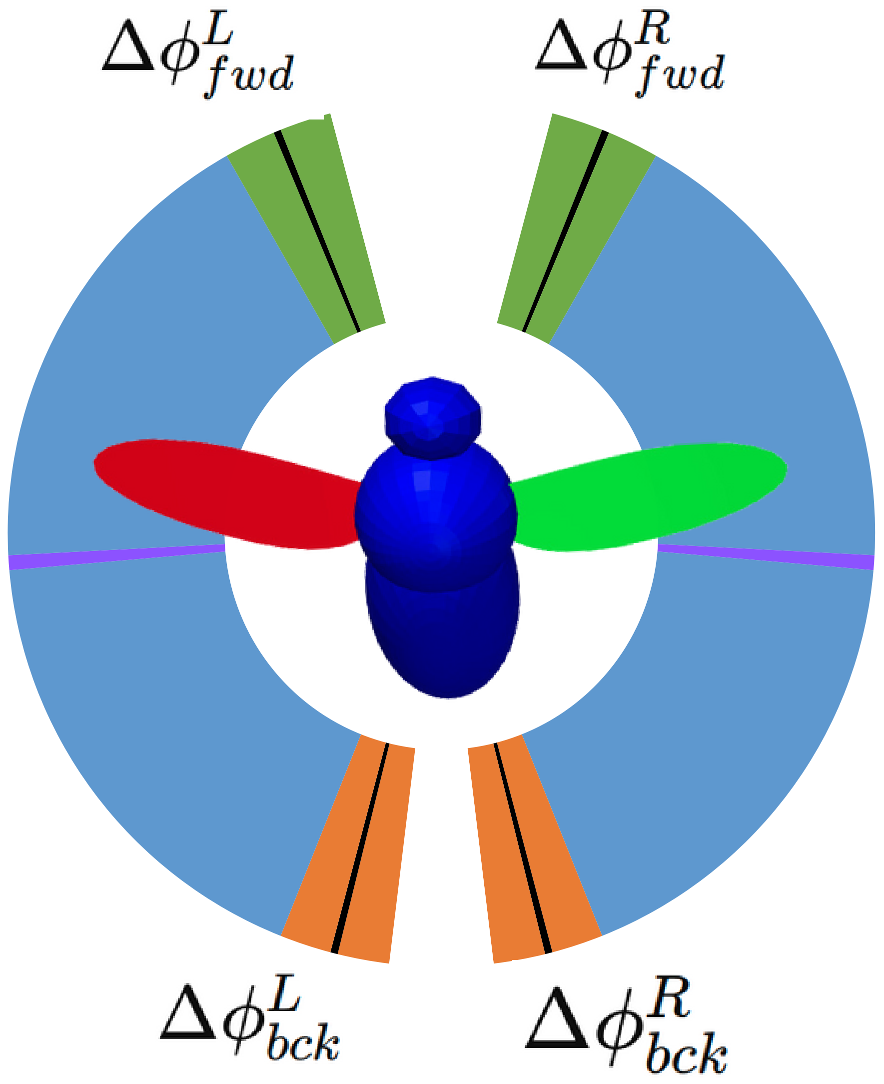
6-DOF simulation of a flying fruit fly with control input

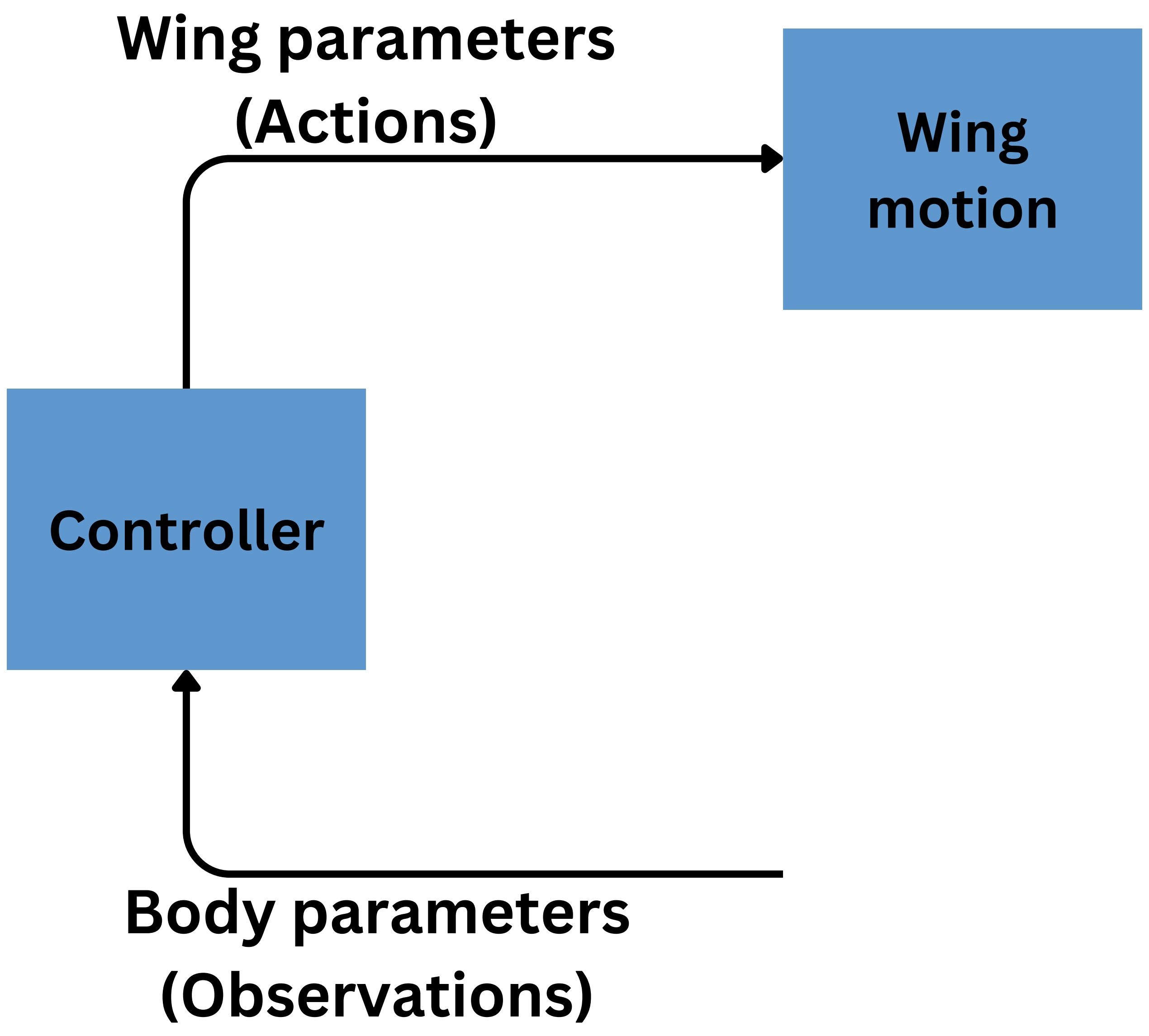


Simulation

6-DOF simulation of a flying fruit fly with control input

- **Prescribed wing motion**



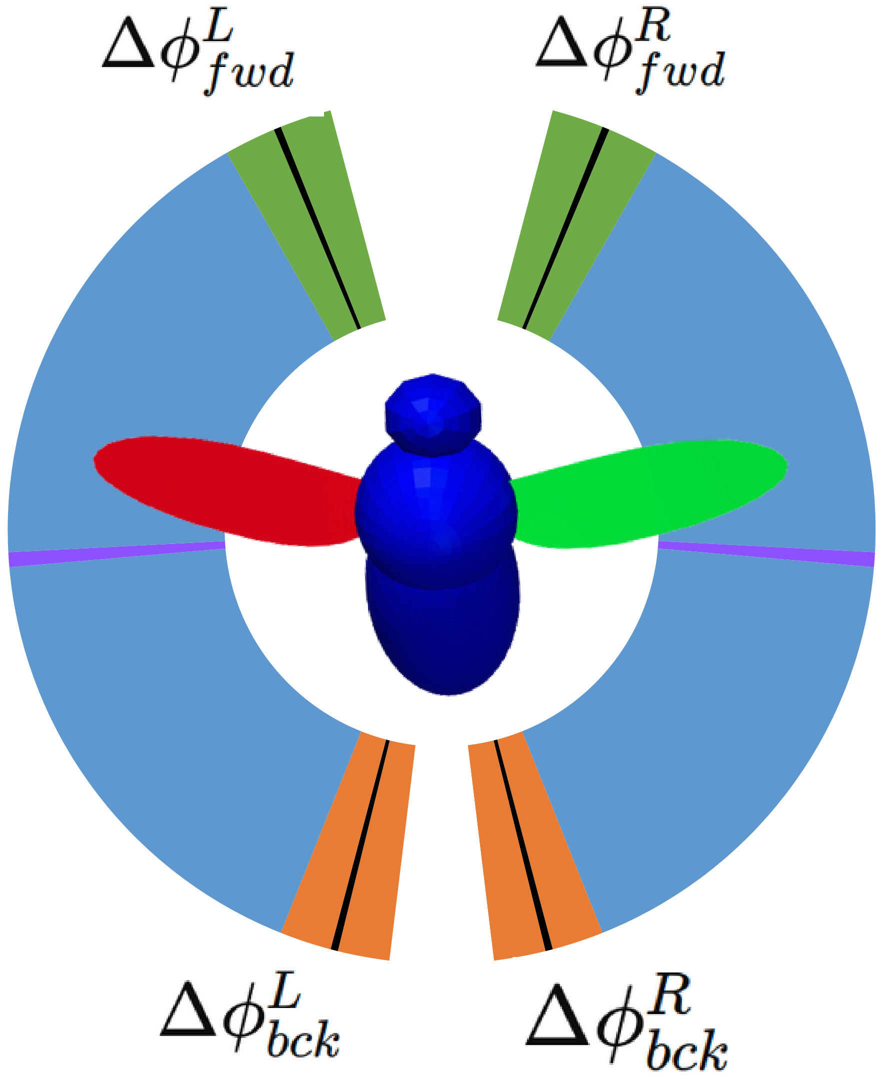


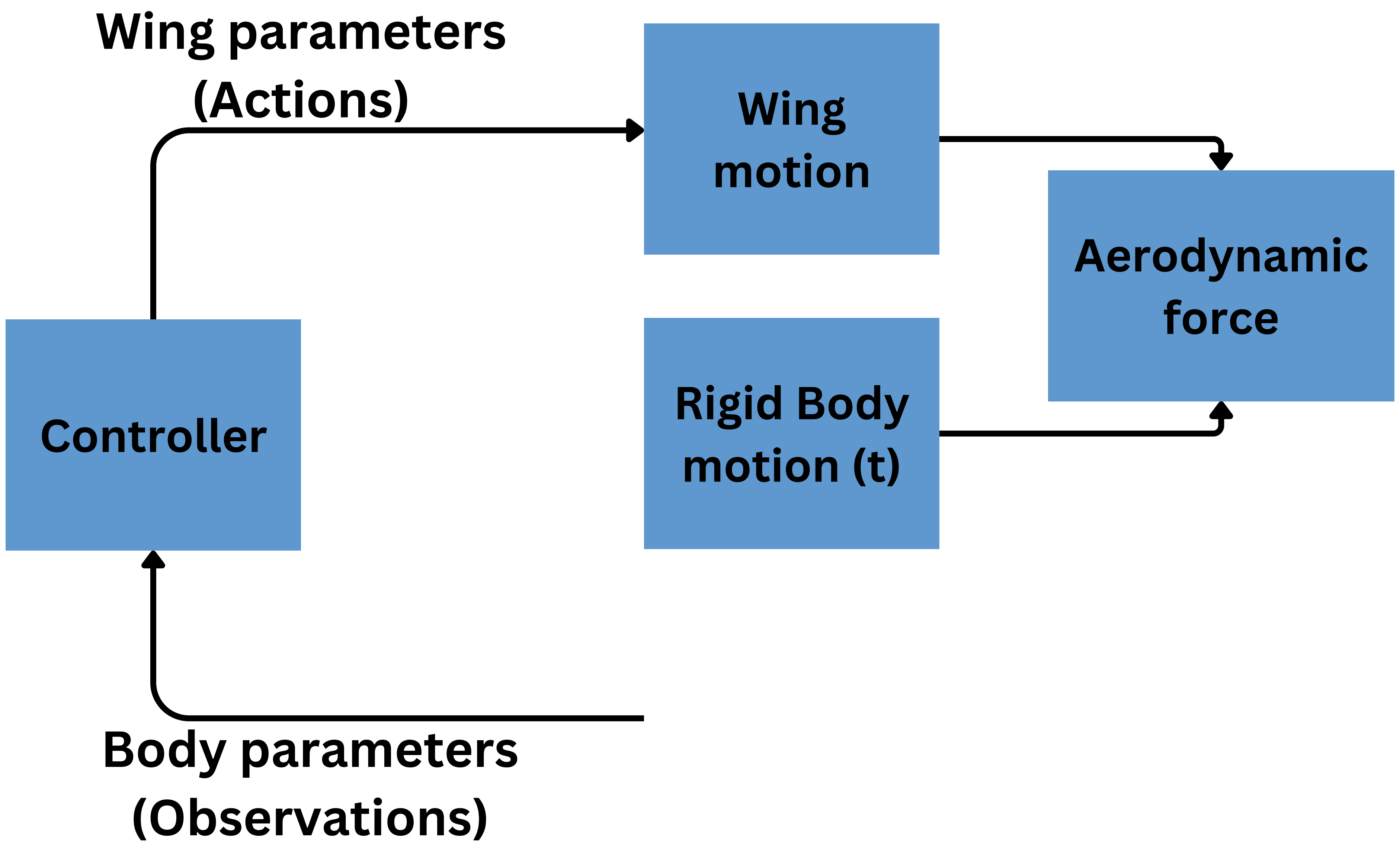
Simulation

6-DOF simulation of a flying fruit fly with control input

- Prescribed wing motion
- **Quasi-steady aerodynamic force model**

$$L = \frac{1}{2}\rho V^2 S C_L(\alpha)$$

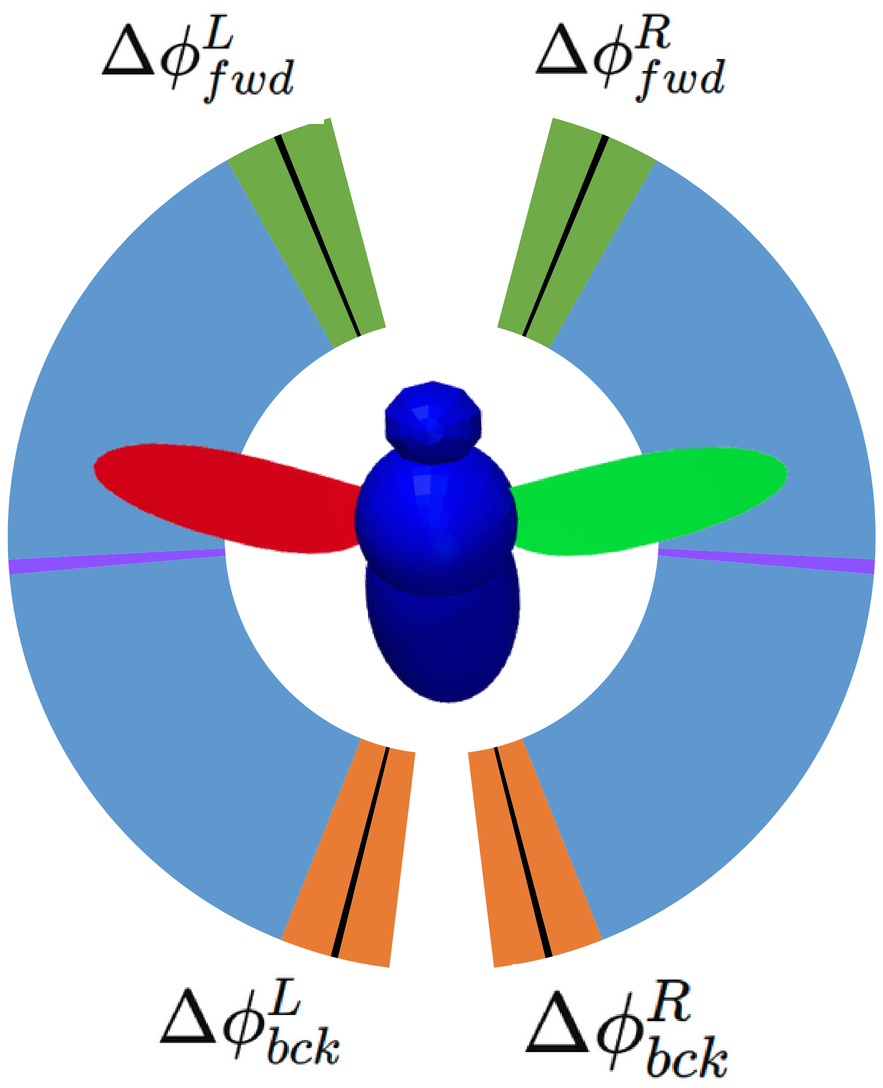




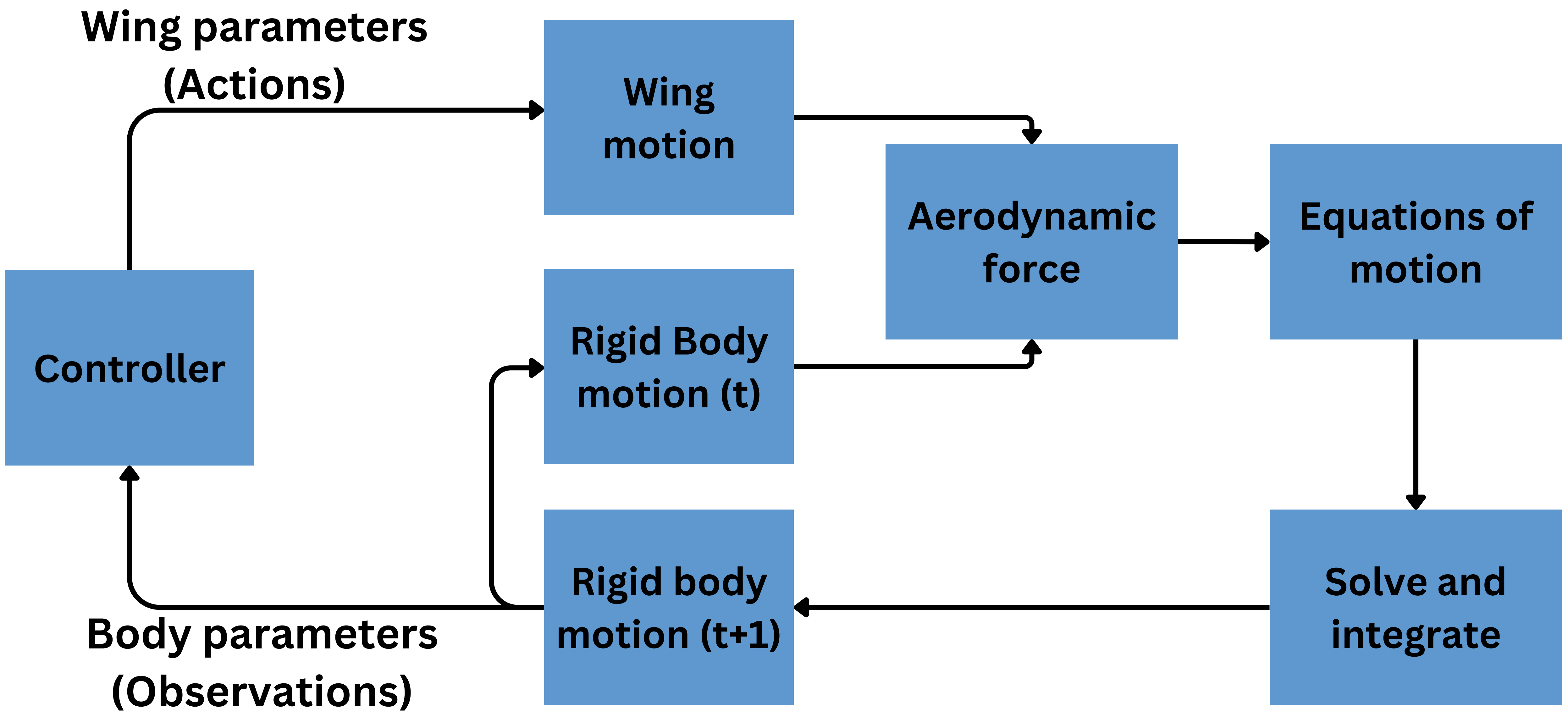
Simulation

6-DOF simulation of a flying fruit fly with control input

- Prescribed wing motion
- Quasi-steady aerodynamic force model
- **EOM + Solver (RK45)**



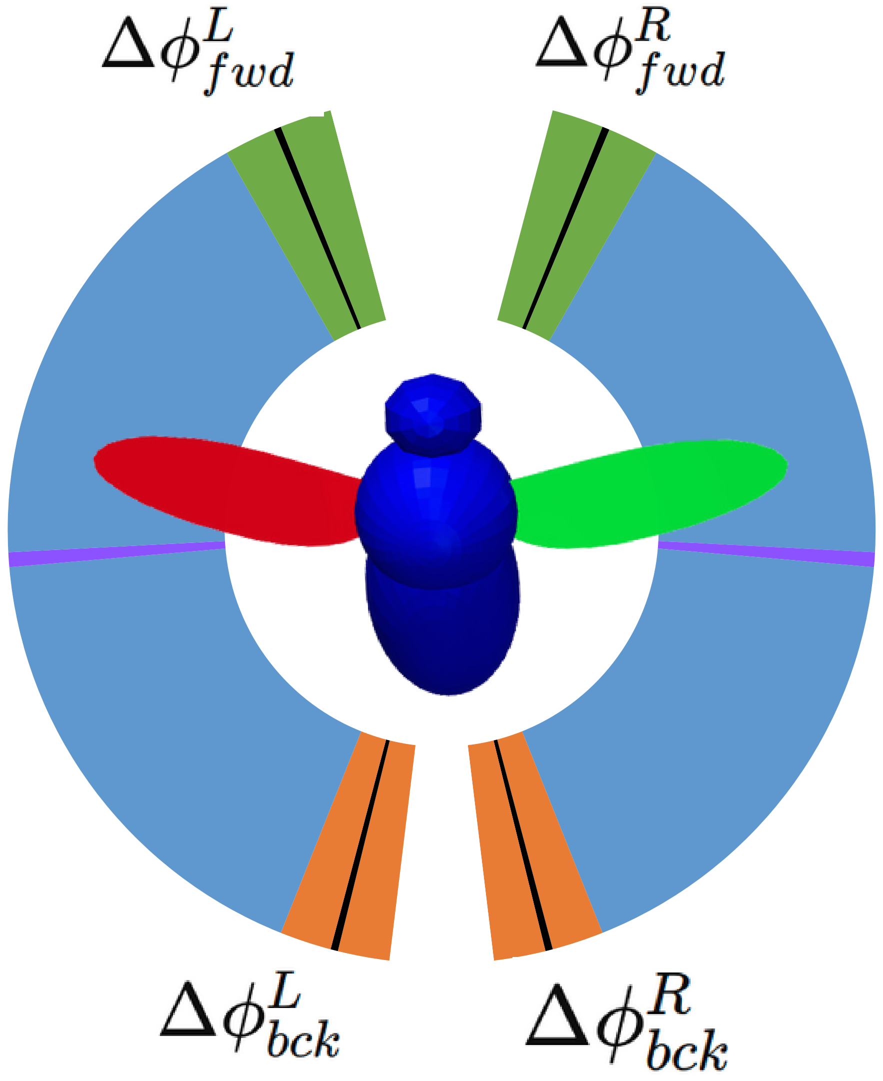
Single Stroke

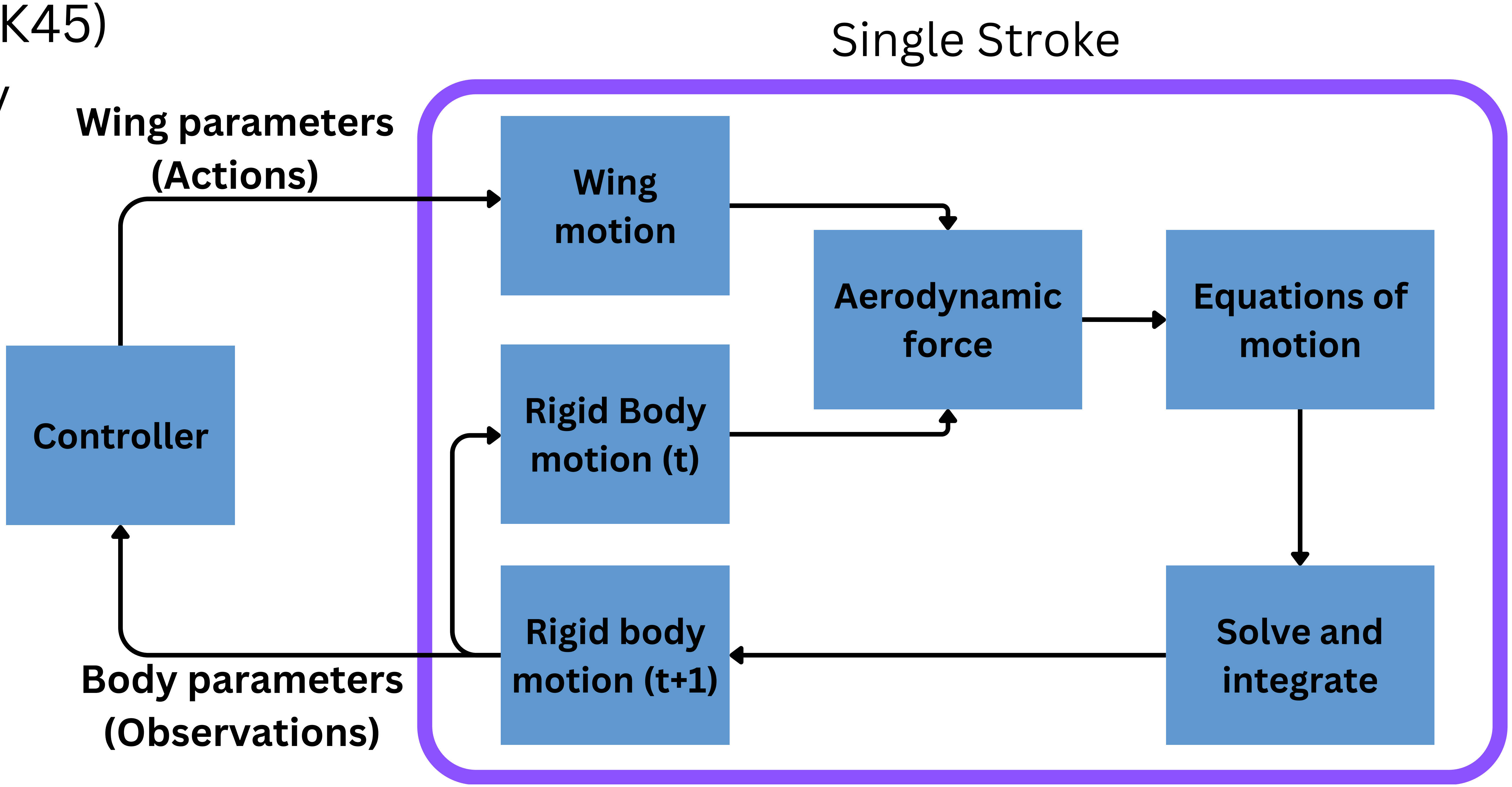


Simulation

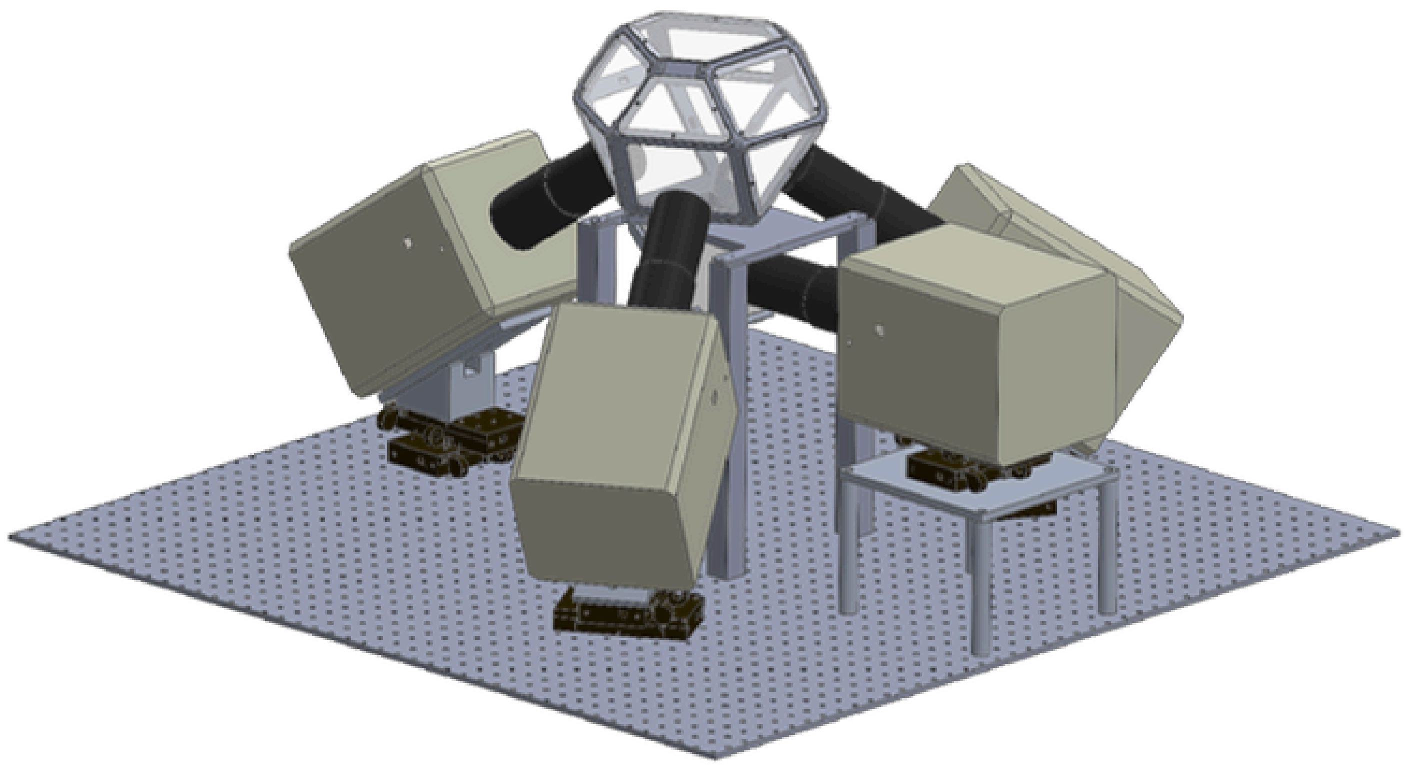
6-DOF simulation of a flying fruit fly with control input

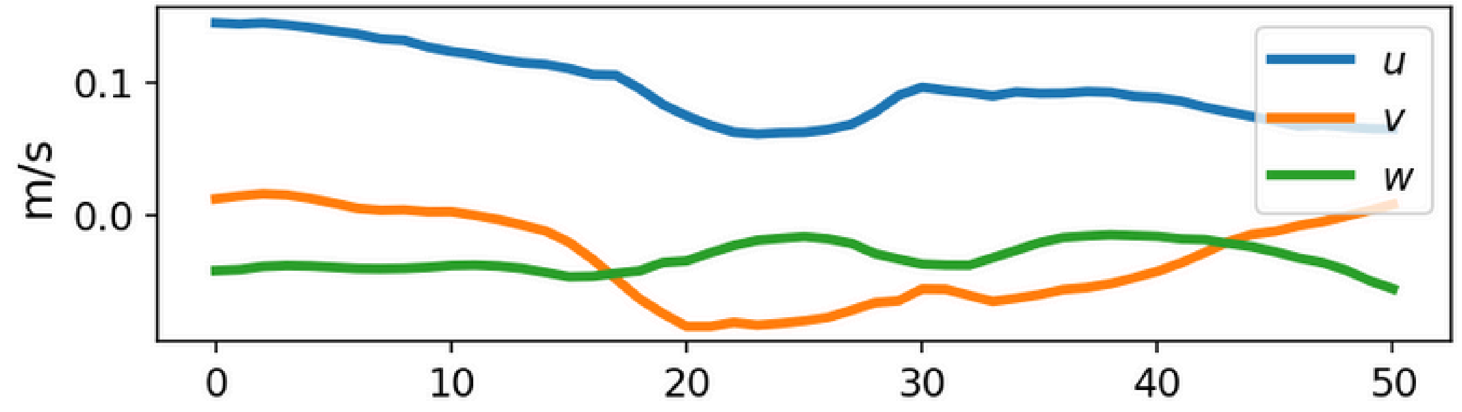
- Prescribed wing motion
- Quasi-steady aerodynamic force model
- EOM + Solver (RK45)
- RL compatibility

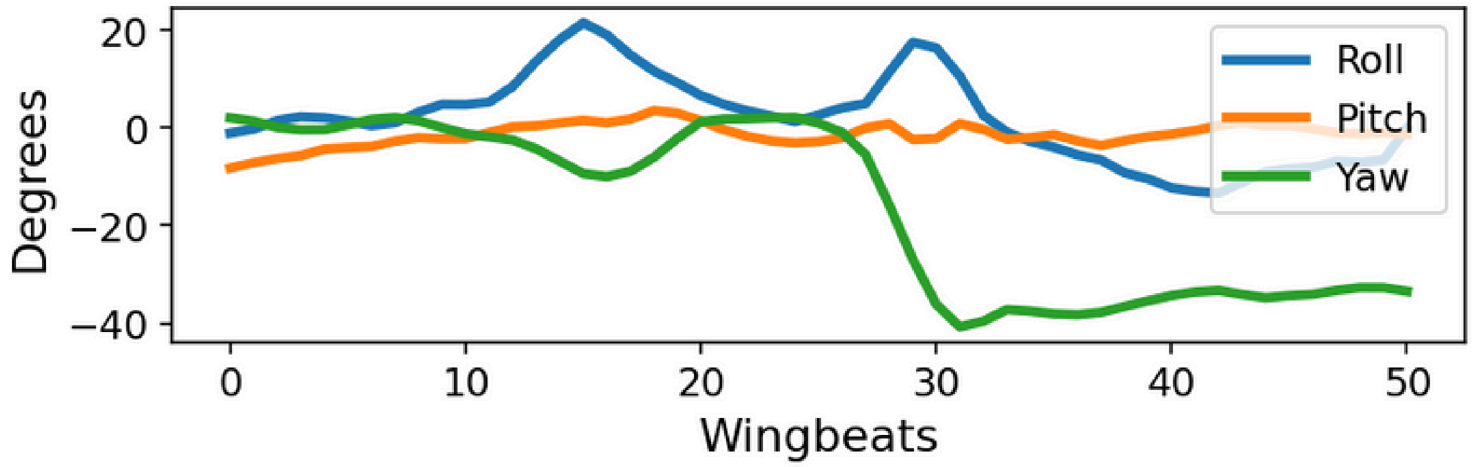


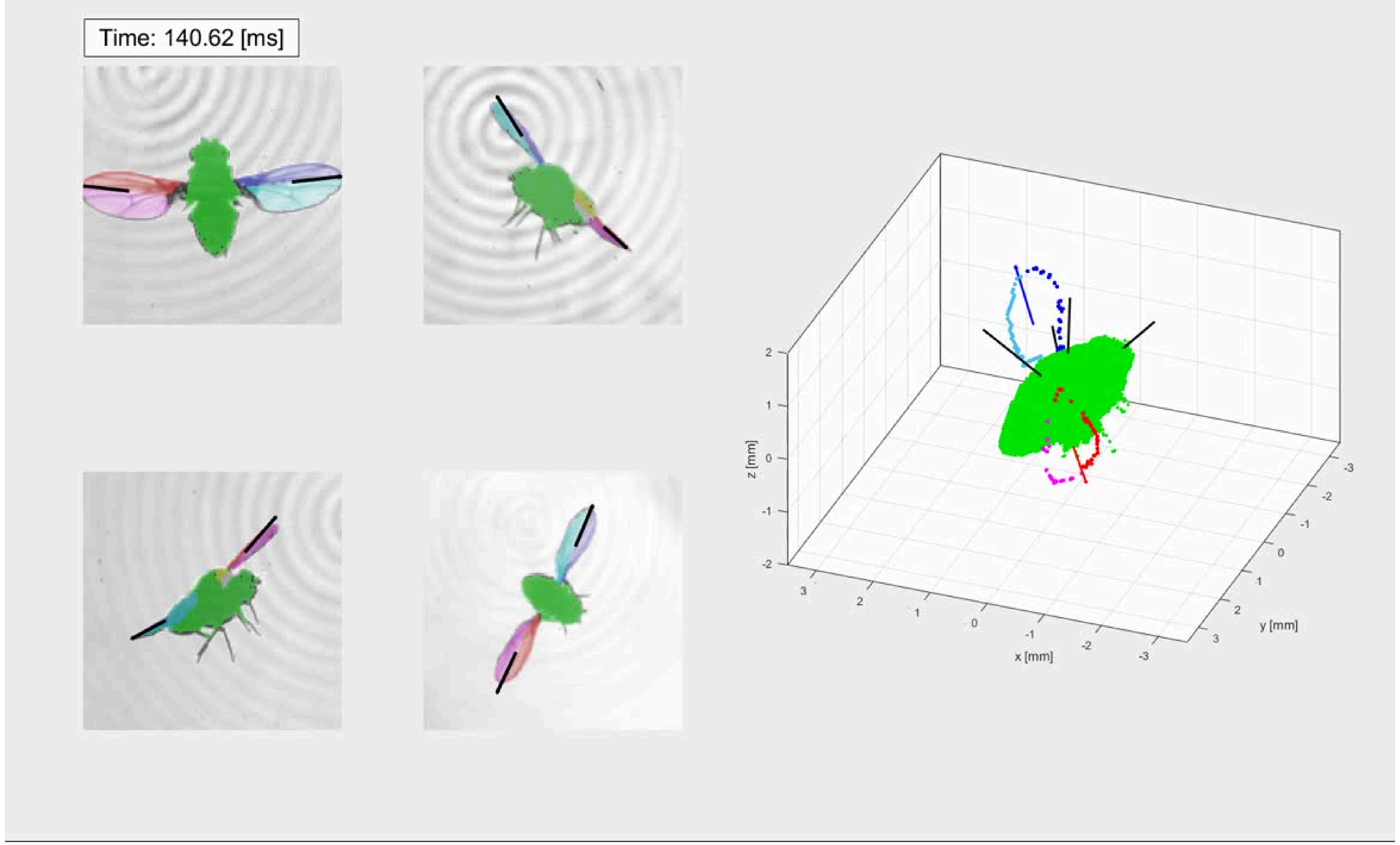


Data Acquisition System and Hull Reconstruction









<u>Maya et al 2023</u>

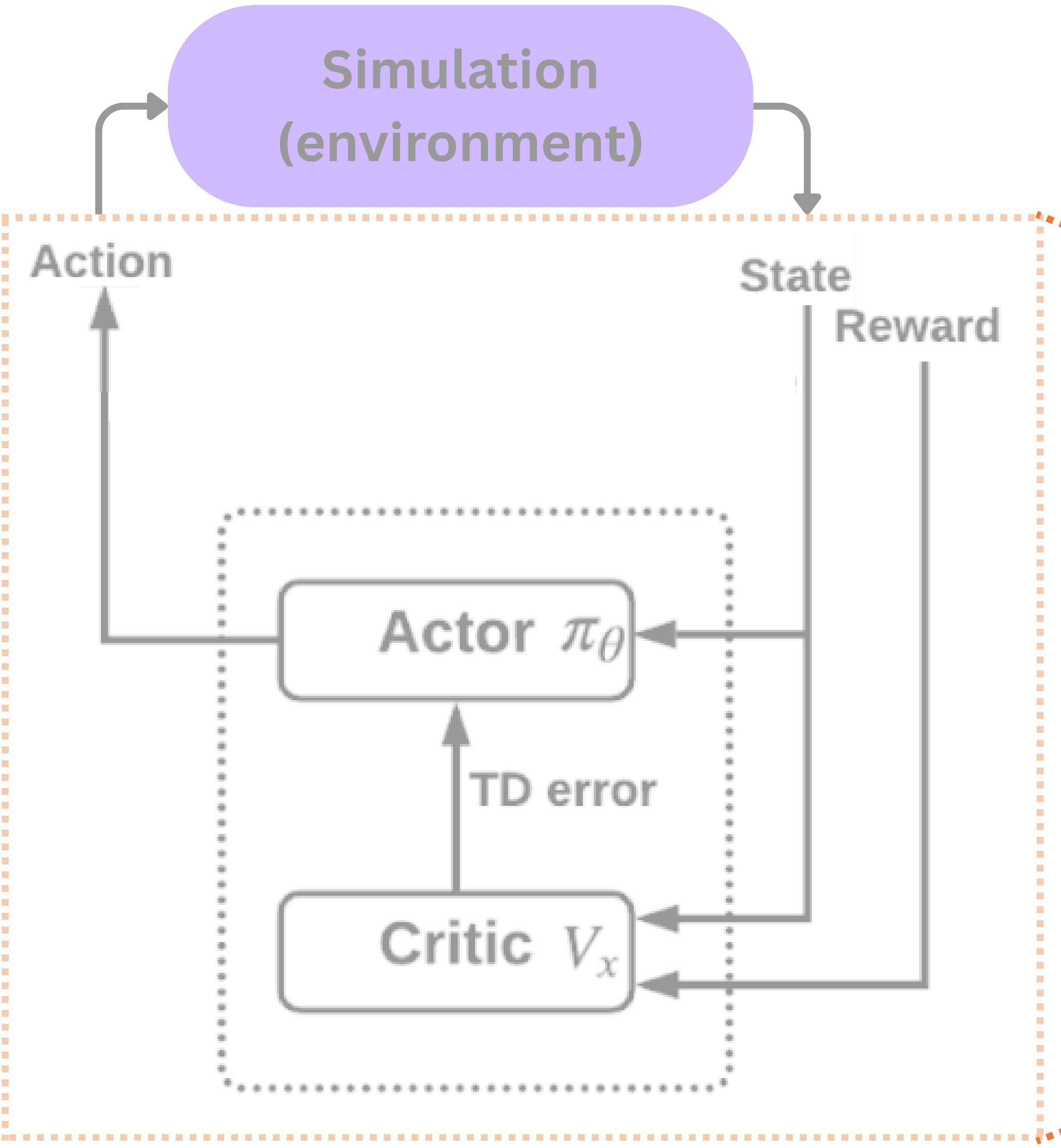
A hull reconstruction–reprojection method for pose estimation of free-flying fruit flies. J Exp Biol

Imitation Learning Algorithm

Proximal Policy Optimization

(Schulman et al 2017)

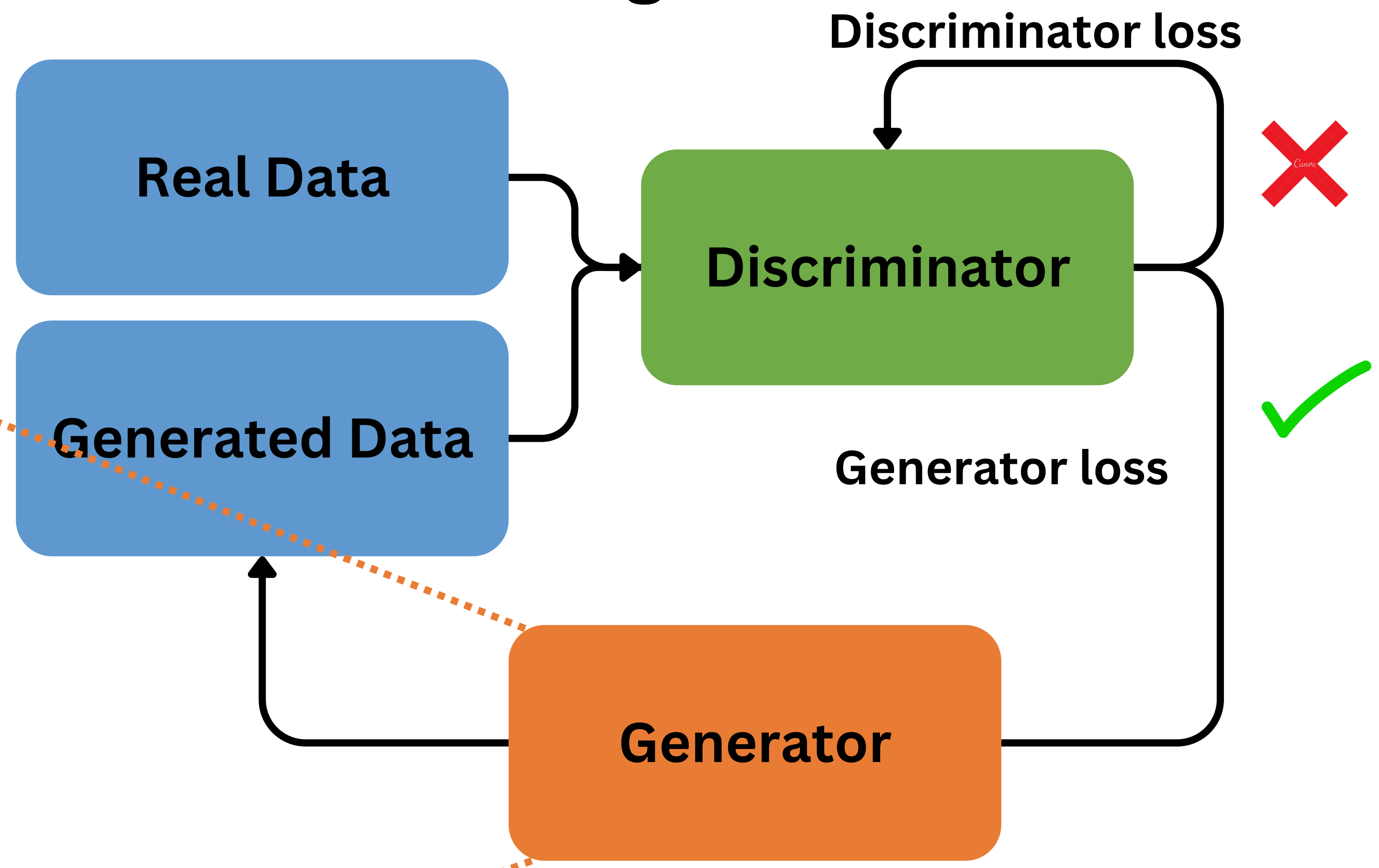
- Policy gradient
- Actor-critic



Generative Adversarial Imitation Learning

(Ho & Ermon 2016)

- GAN Architecture
- Imitation Learning



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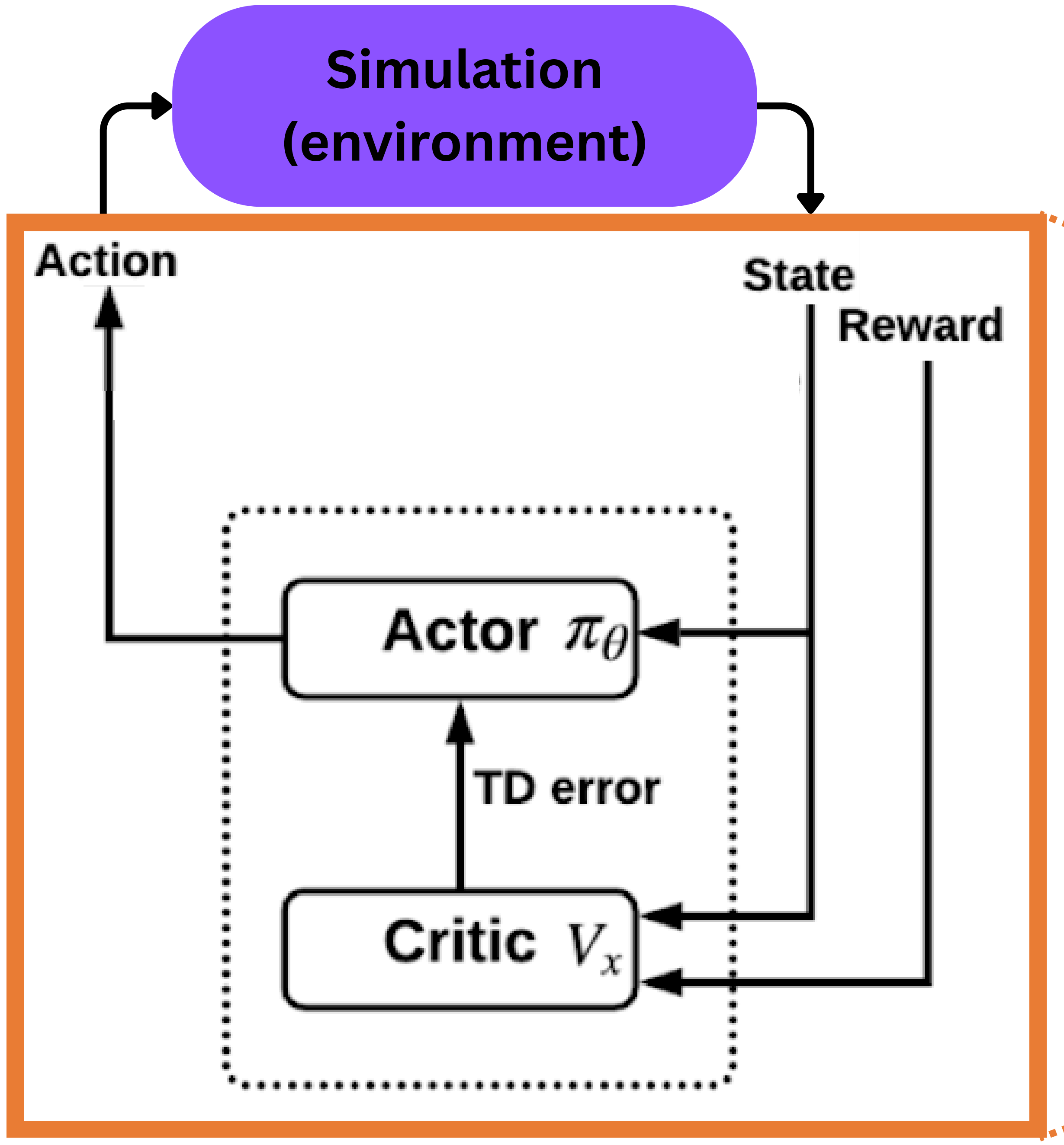

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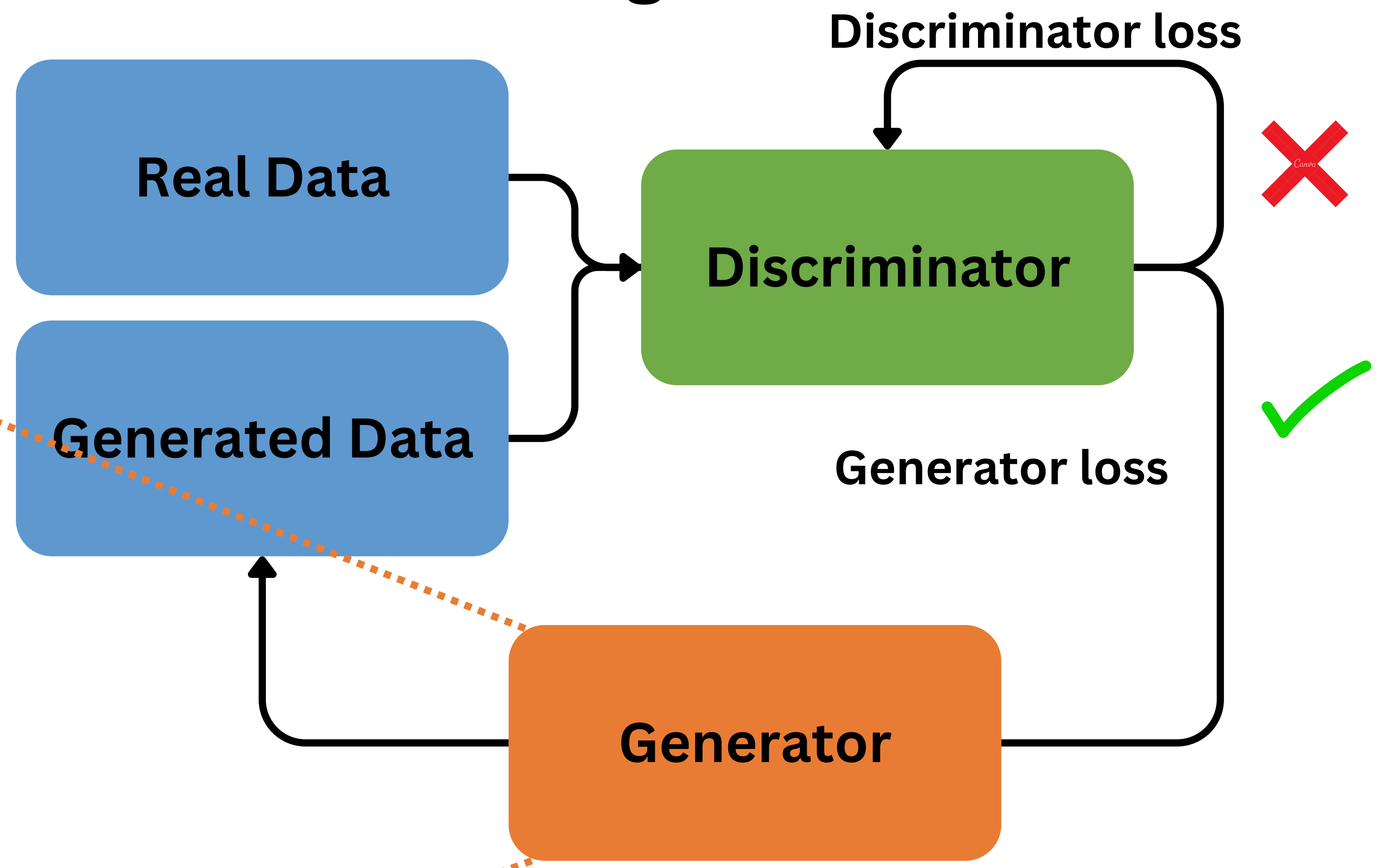

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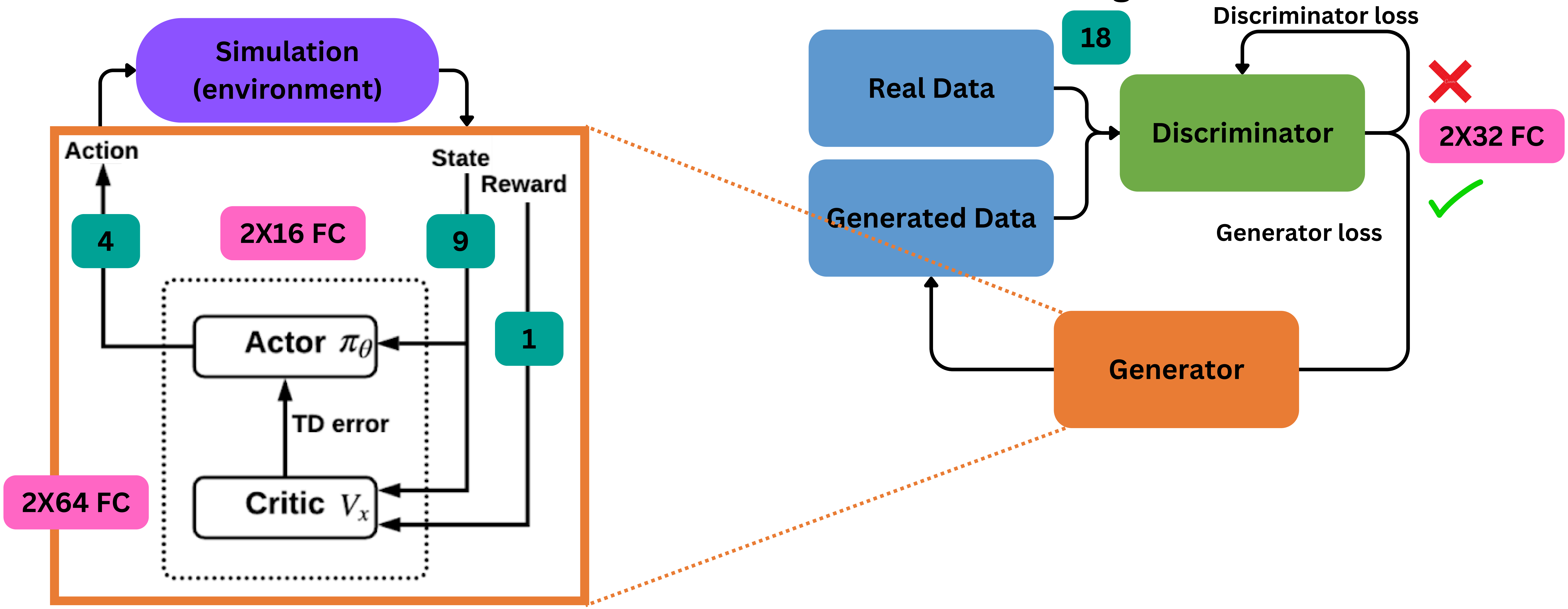
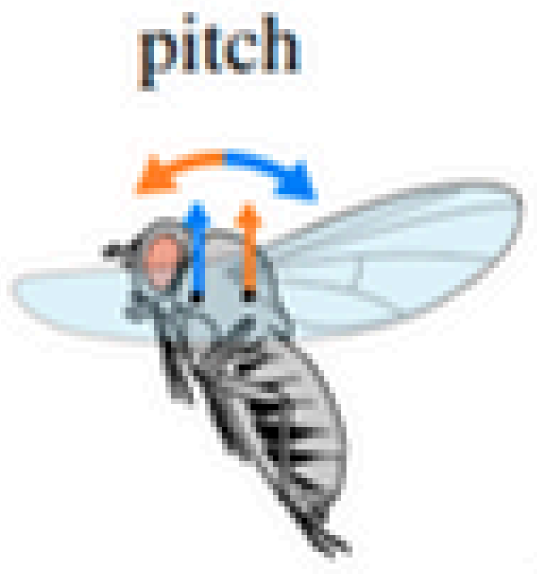
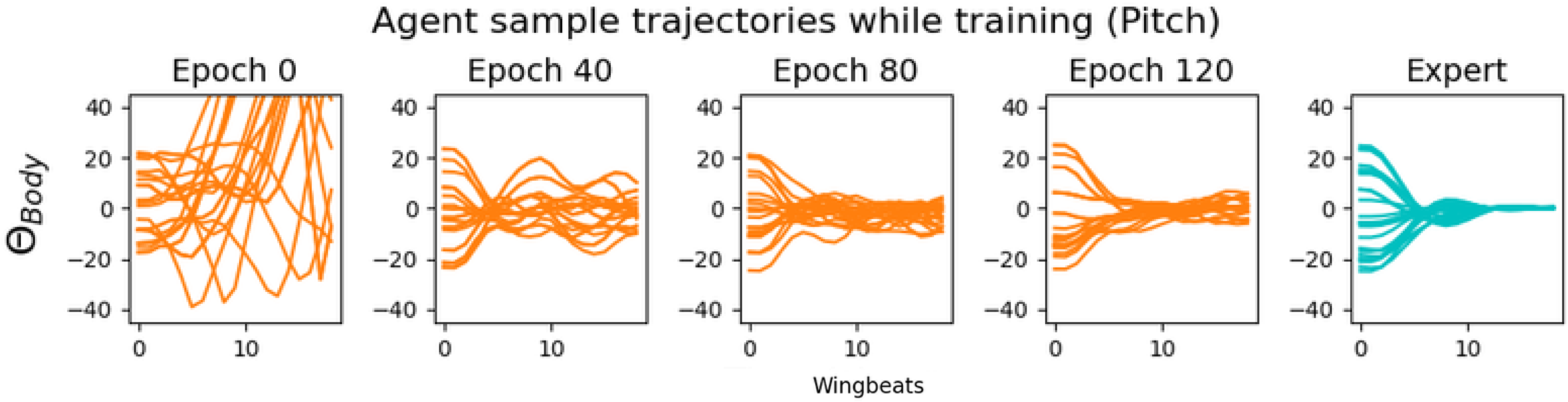


Results - Learning from a PID "Expert"

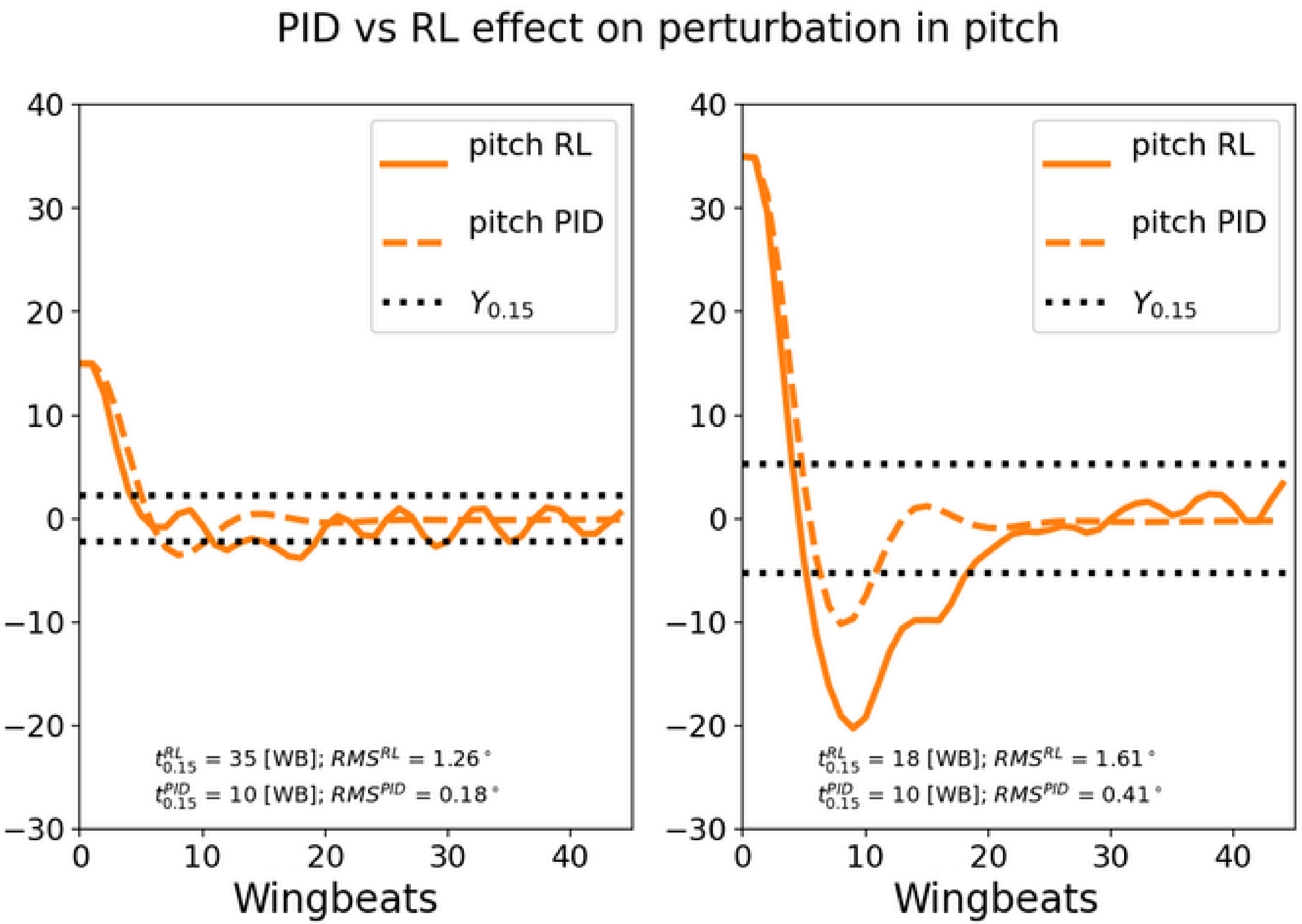
- Using trajectories from PID controlled simulated flies
- Hyper Parameter tuning ✅
- Time to convergence ~70-120 epochs





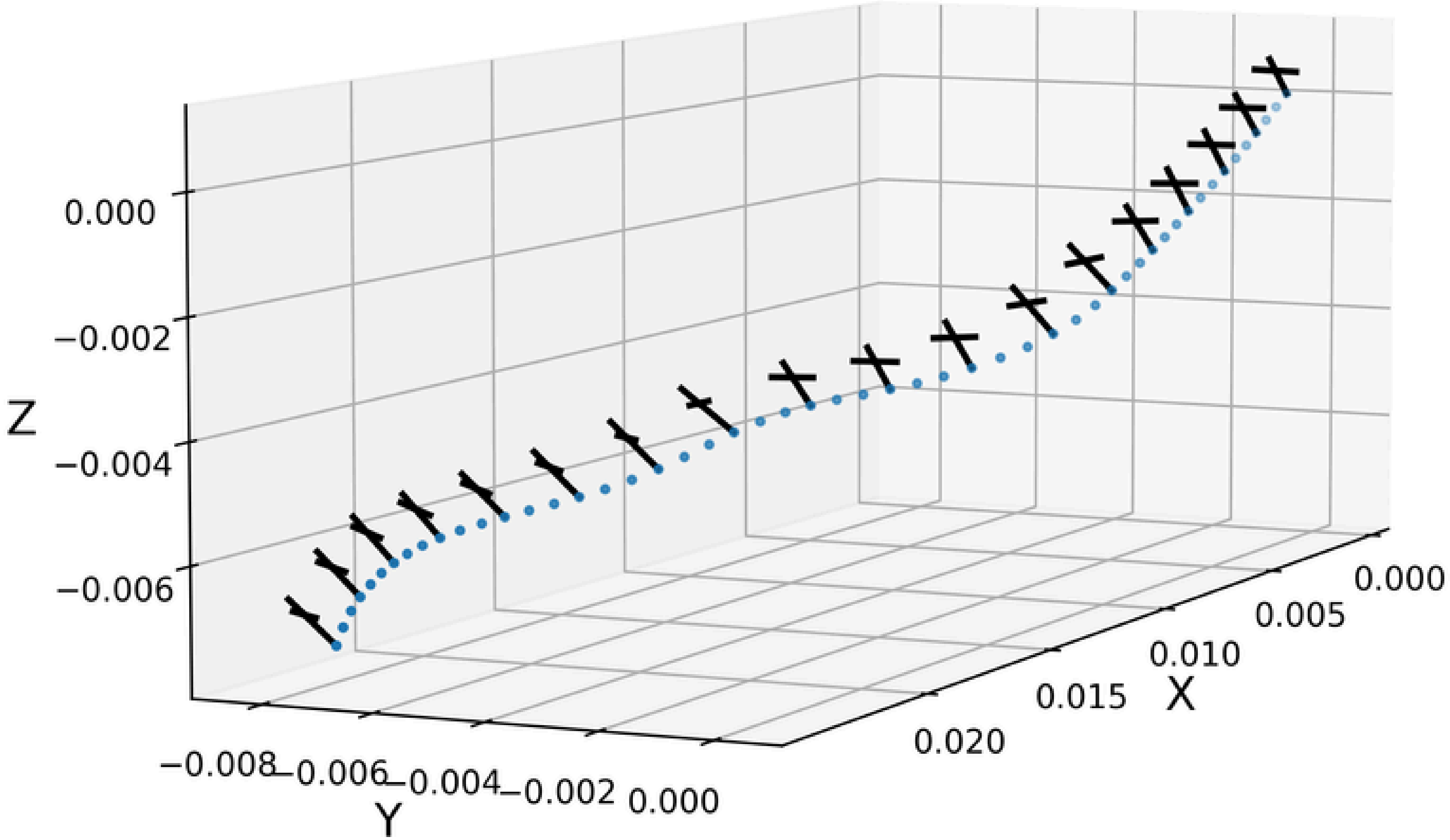
Results - Learning from a PID “Expert”

- Testing the trained agent under pitch perturbations
- Comparing performance to PID “expert”



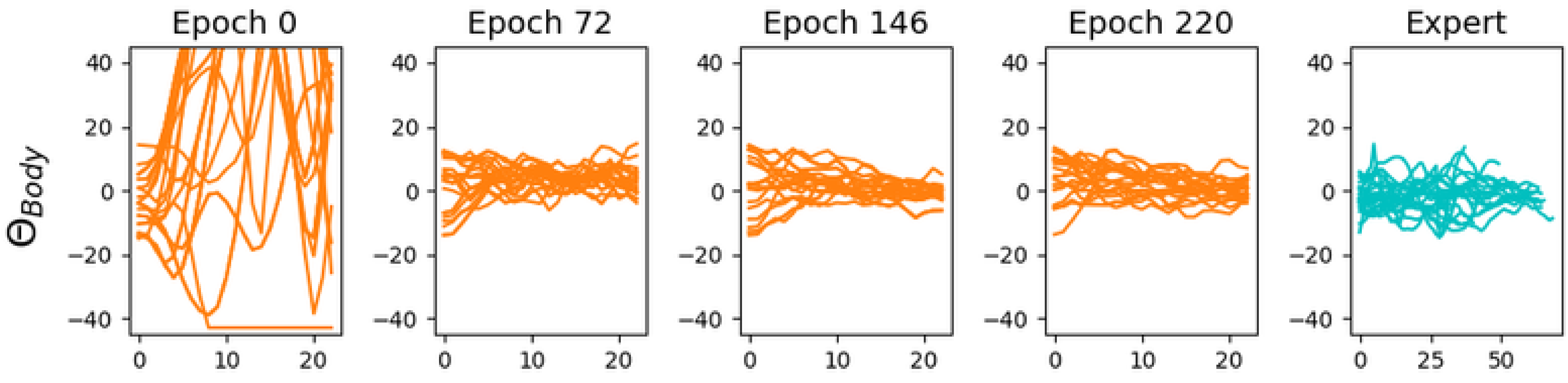
Results - Measured Raw Data

- Data Collected for the MFL Dataset:
    - >1000 Trajectories
    - >41K Individual wingbeats



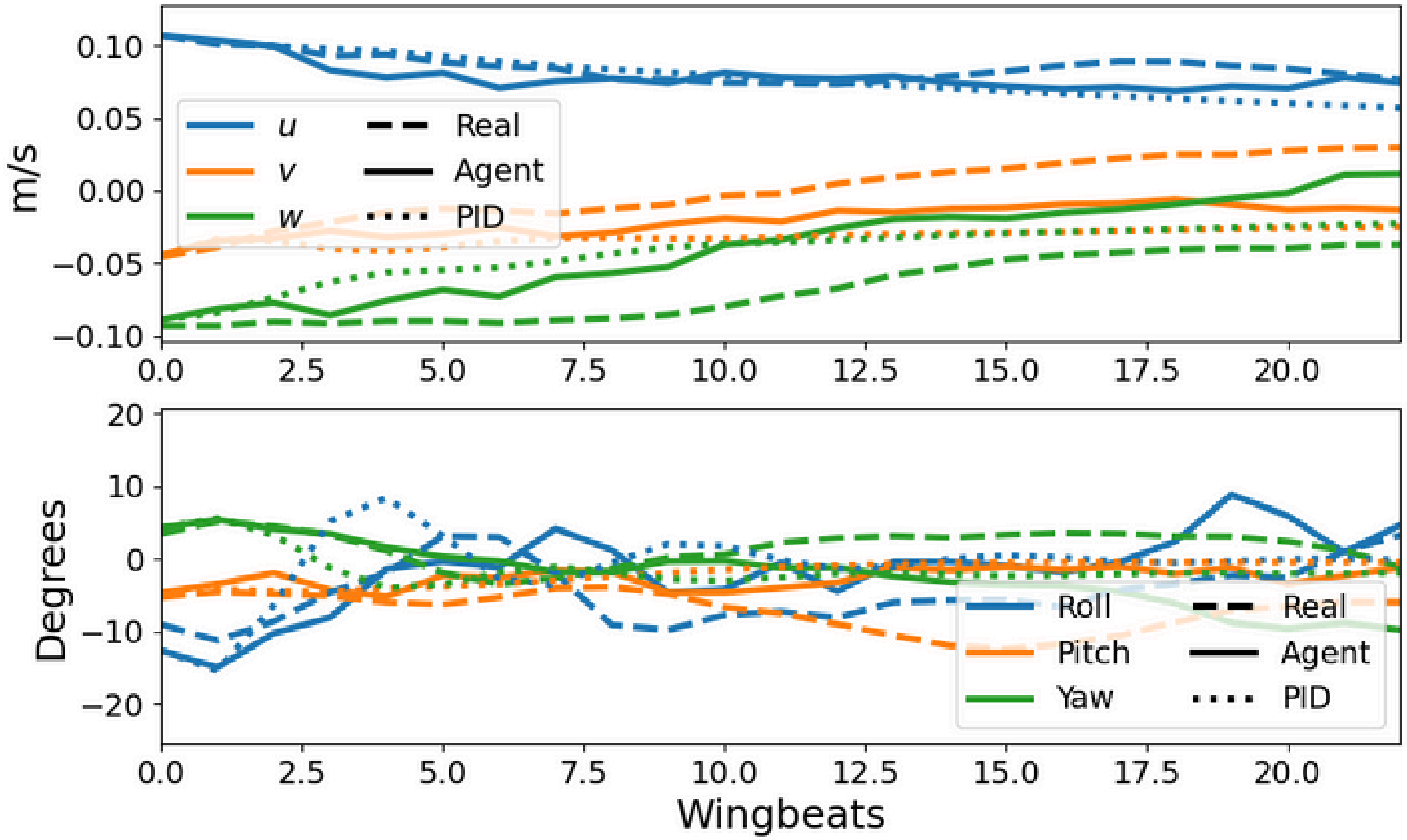
Results - Learning from the raw data

- Convergence at 120-140
- Controller was able to sustain stable flight



Results - Learning from the raw data

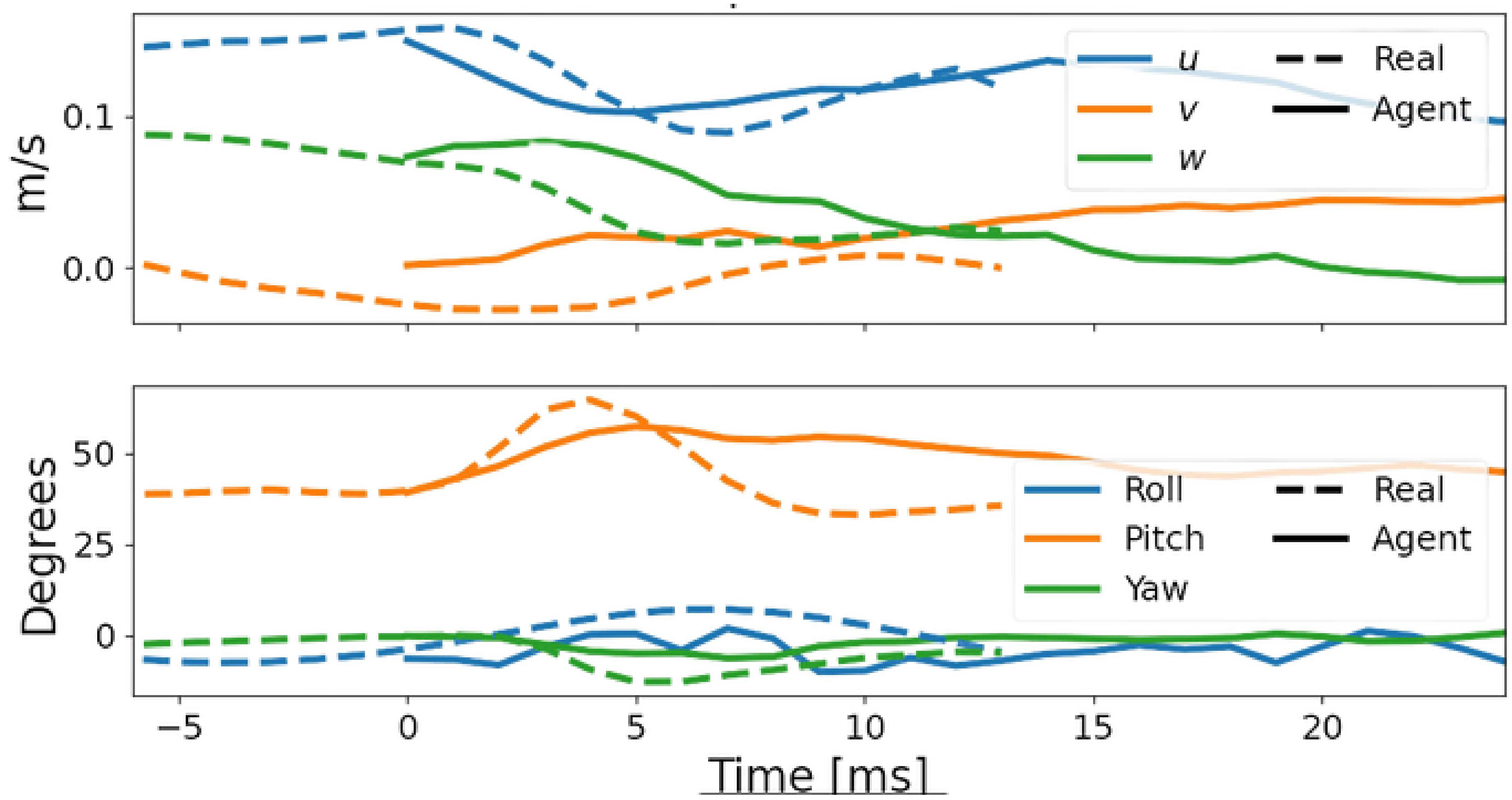
- Stabilizes Pitch and Roll
- Dampens yaw
- Maintains velocity and altitude



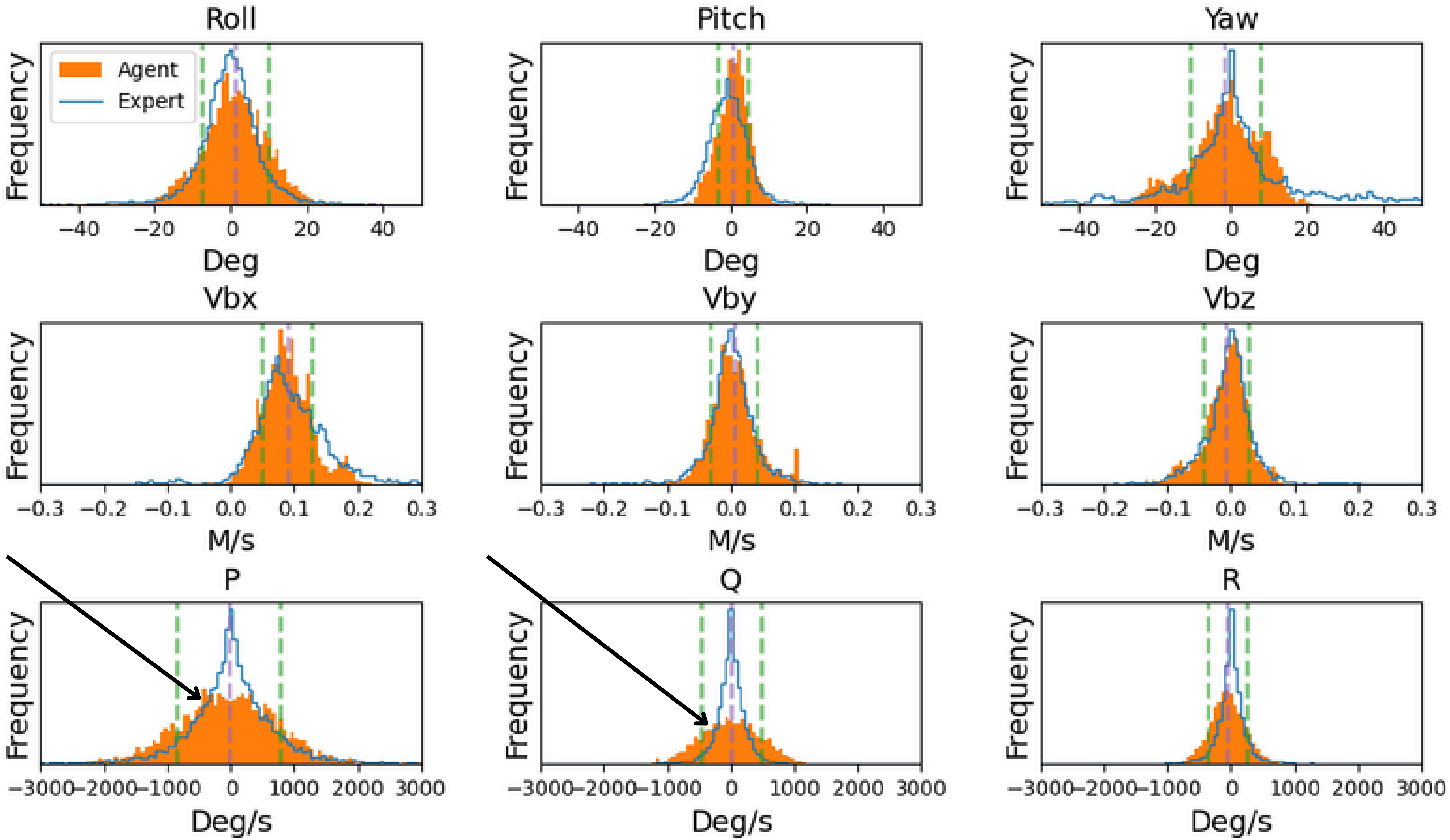
Results - Learning from the raw data: Unseen Conditions

Pitch perturbation

(Beatus et al 2015)

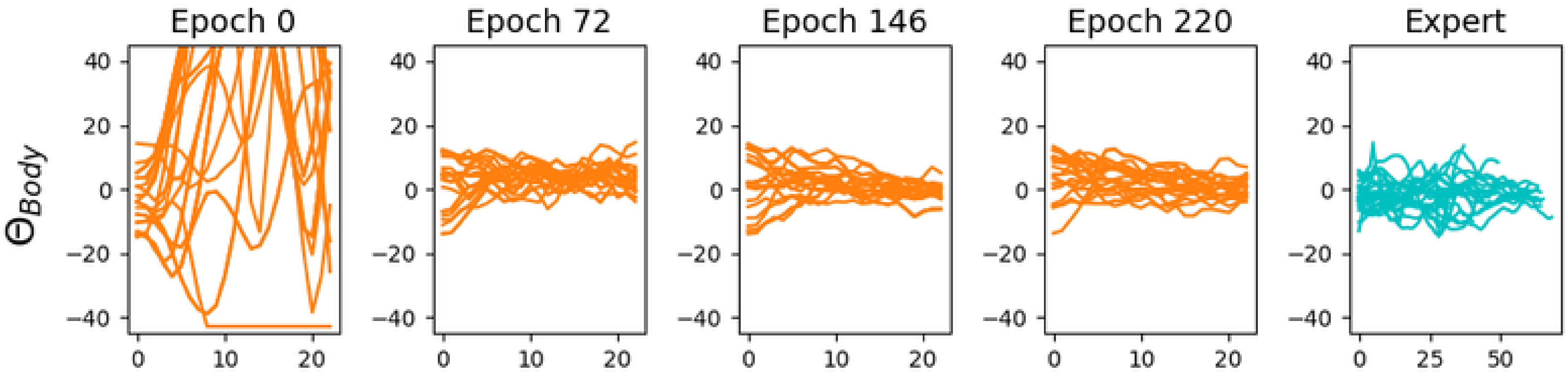


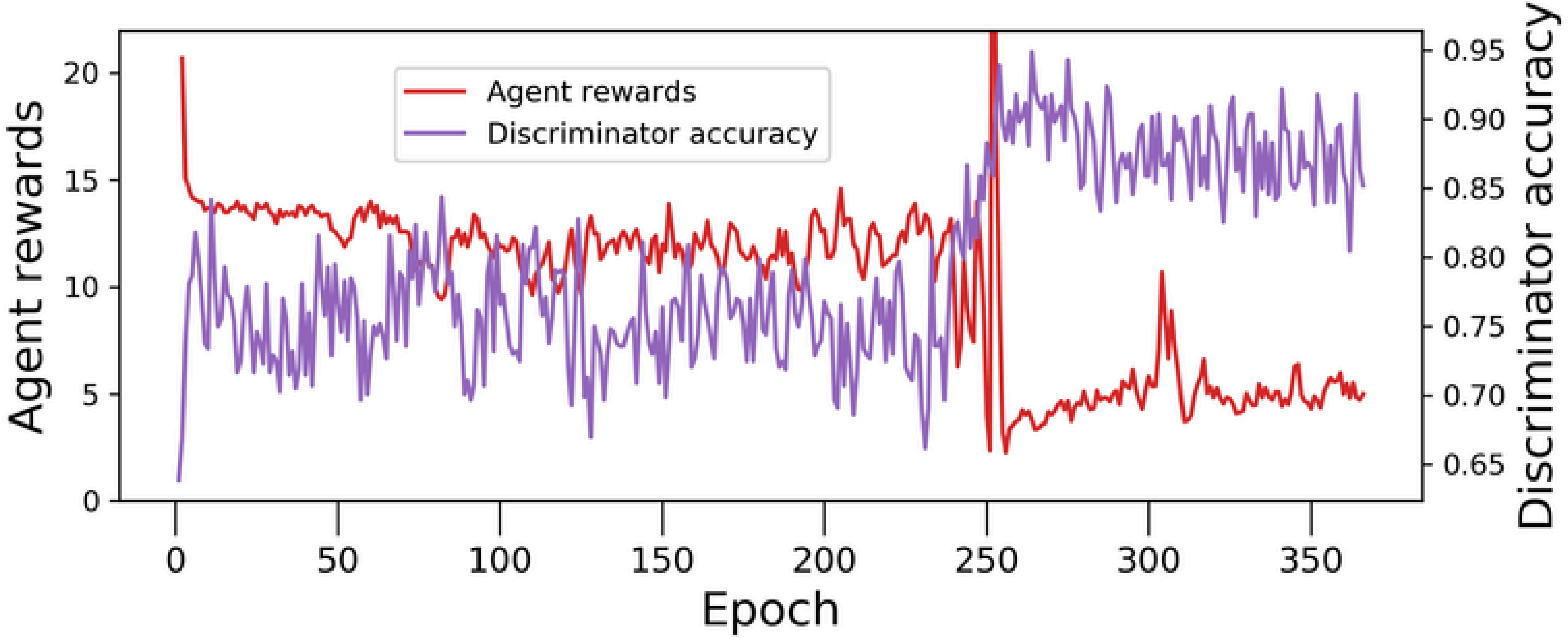
Results - Learning from the raw data

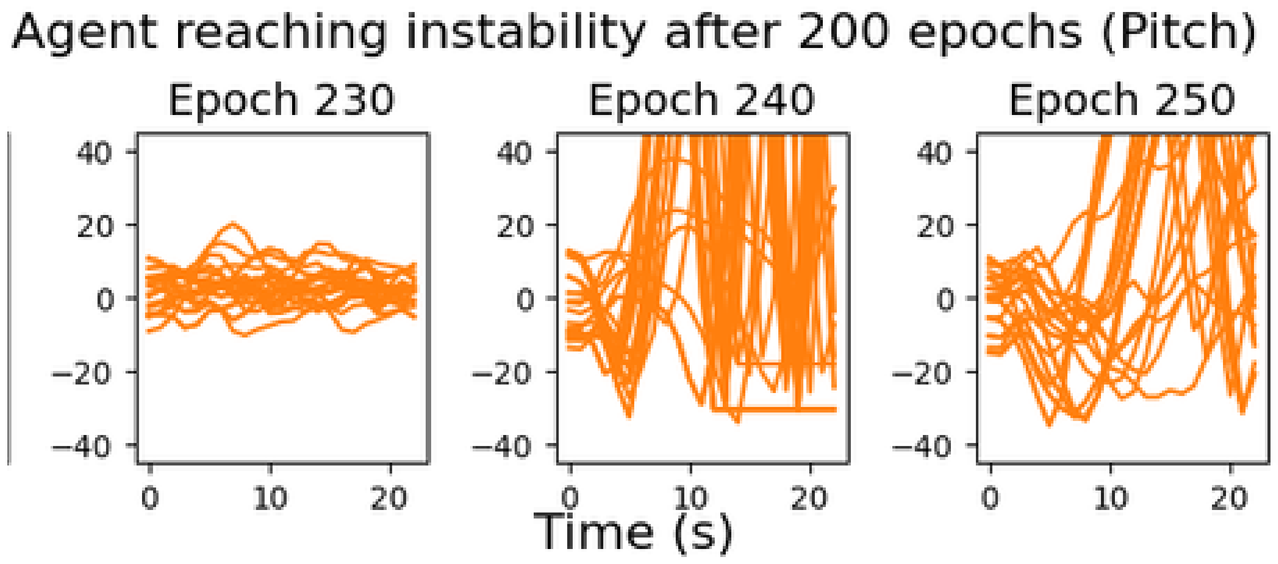


Results - Learning from the raw data

- GAN collapses at ~240
- Hyper-Parameter tuning has no effect







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Thank You

Questions?

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