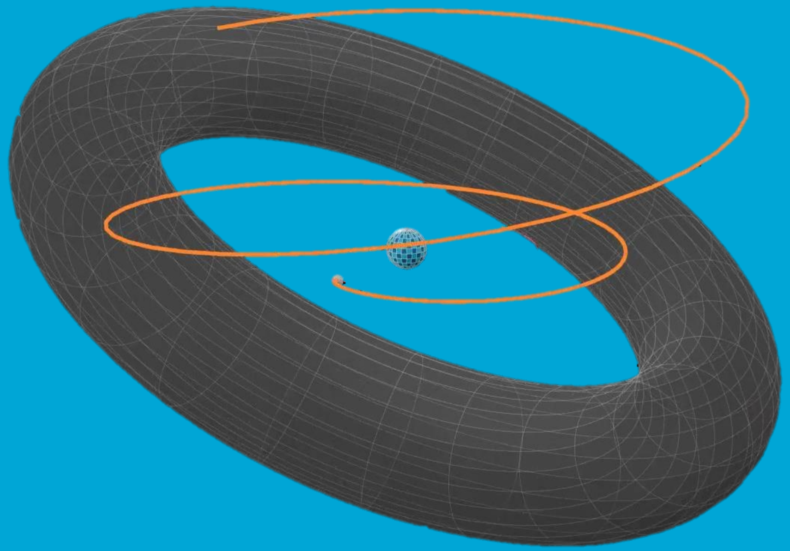
Autonomous Guidance and Control for Drones and Spacecrafts



G&CNETs: Guidance and Control Networks

TU Delft & ESA Advanced Concepts Team

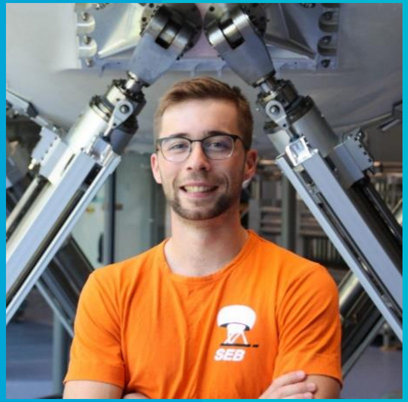
Robin Ferede & Sebastien Origer

14 September, 2022

Robin

2020: Internship at the ACT	Feasibility study of G&CNETs on quadcopters (SIMULATION)
2021 - 2022: MSc TU Delft & ACT	Applying G&CNETs on quadcopters (REAL FLIGHTS)

Sebastien



2021: Internship at the ACT	Feasibility study of G&CNETs for spacecraft rendezvous using the Backward Generation of Optimal Samples (SIMULATION)
2022 - ongoing: MSc TU Delft & ACT	Working towards time-optimal flight using G&CNETs on quadcopters (REAL FLIGHTS)

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General overview

G&CNETs: Guidance and Control Networks

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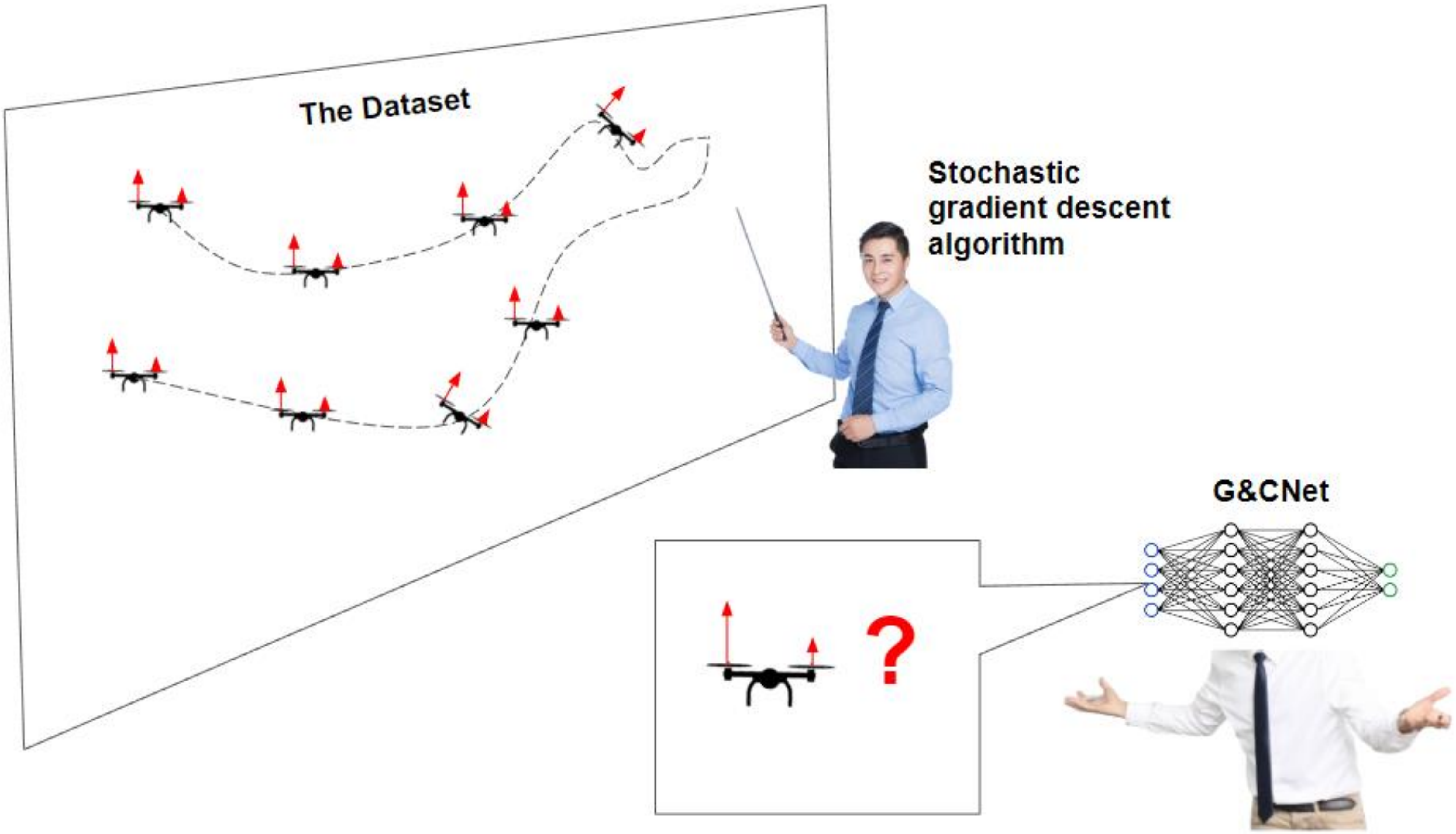
The Dataset
Stochastic
gradient descent
algorithm
G&CNet
?

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Power-optimal quadrotor flight

Robin Ferede

TU Delft & ESA Advanced Concepts Team

14 September, 2022

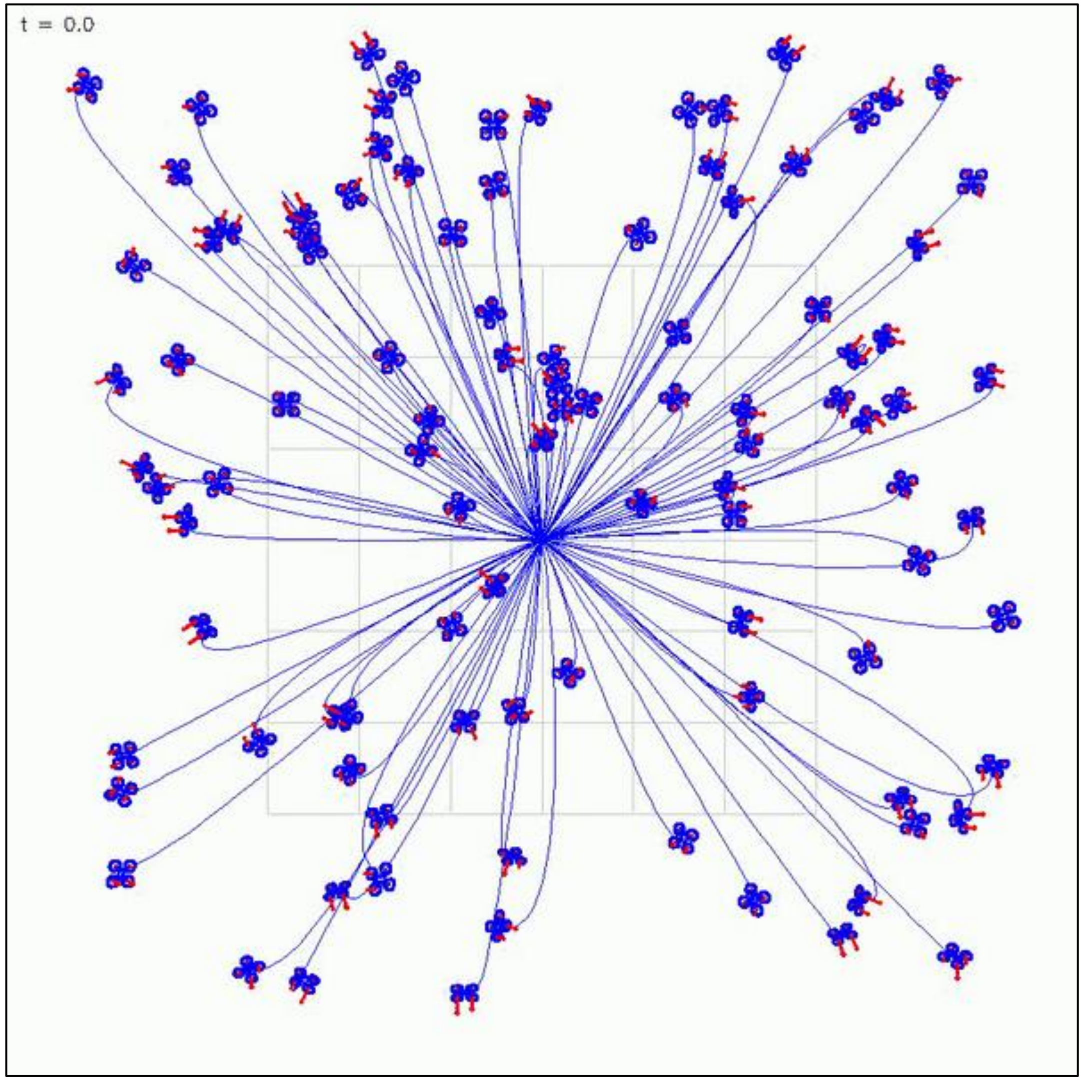
Power optimal control

$$\underset{\mathbf{u},T}{\text{minimize}} \quad J(\mathbf{u},T) = \int_0^T ||\mathbf{u}(t)||^2 dt$$

$$\text{subject to} \quad \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u})$$

$$\mathbf{x}(0) = \mathbf{x}_0$$

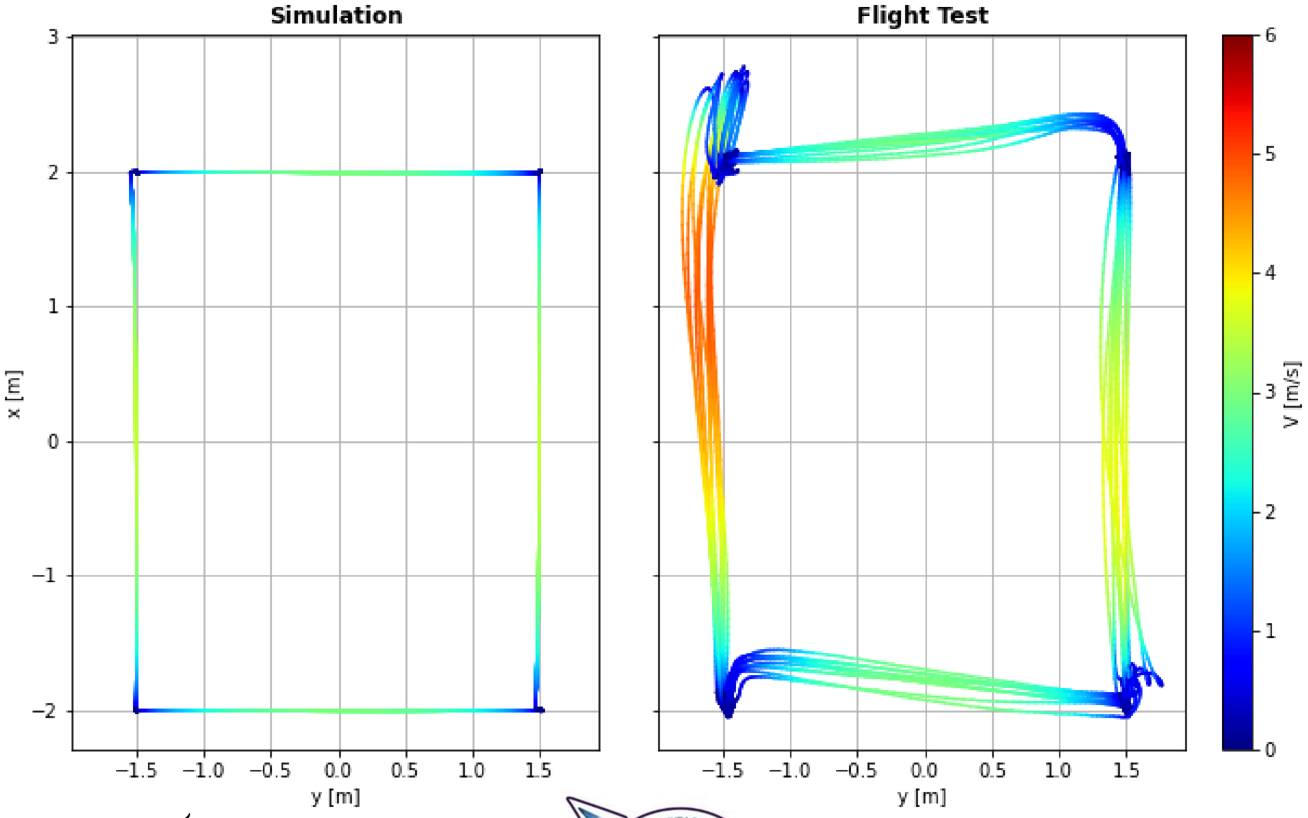
$$\mathbf{x}(T) \in S$$

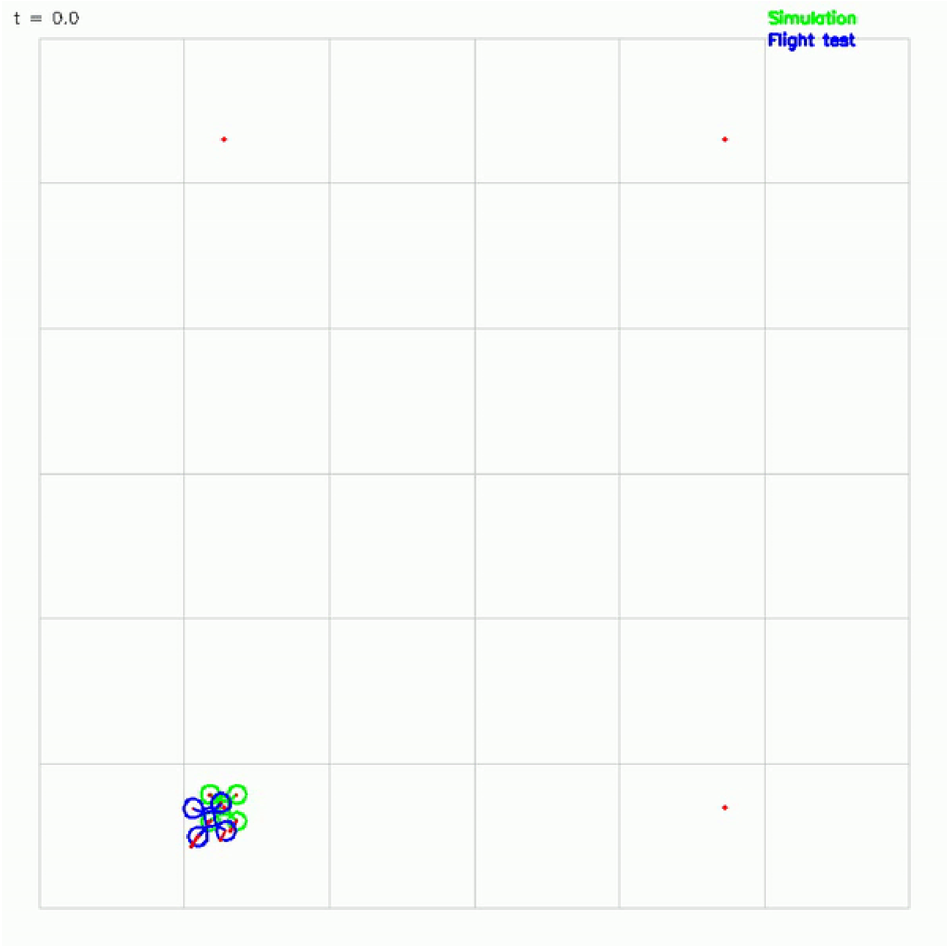


TU Delft

Results Master Thesis

1: Identification of unmodeled effects





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Results Master Thesis

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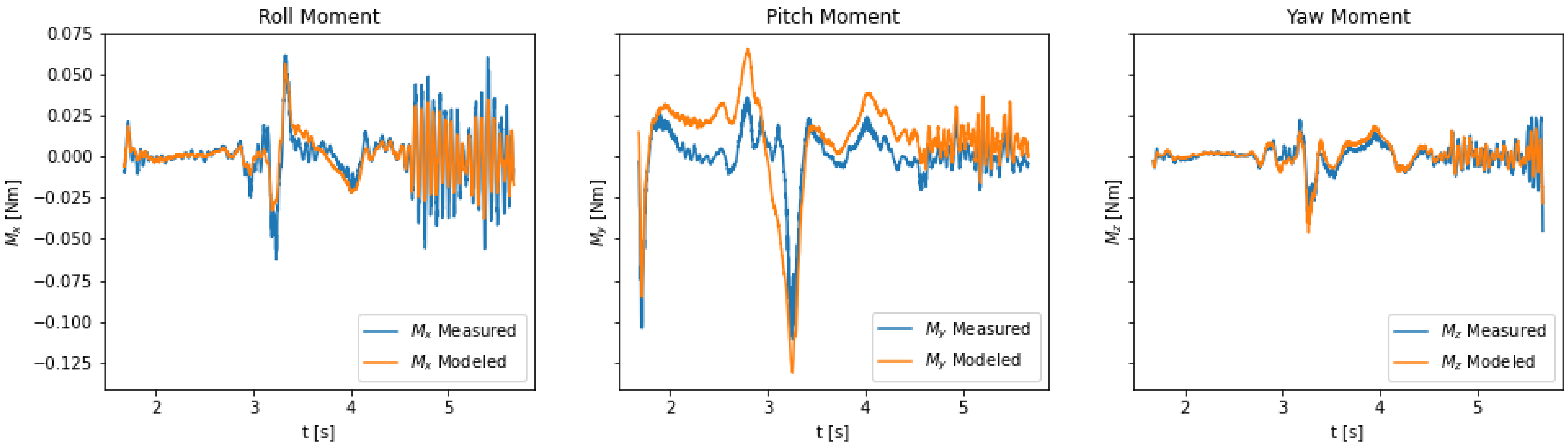

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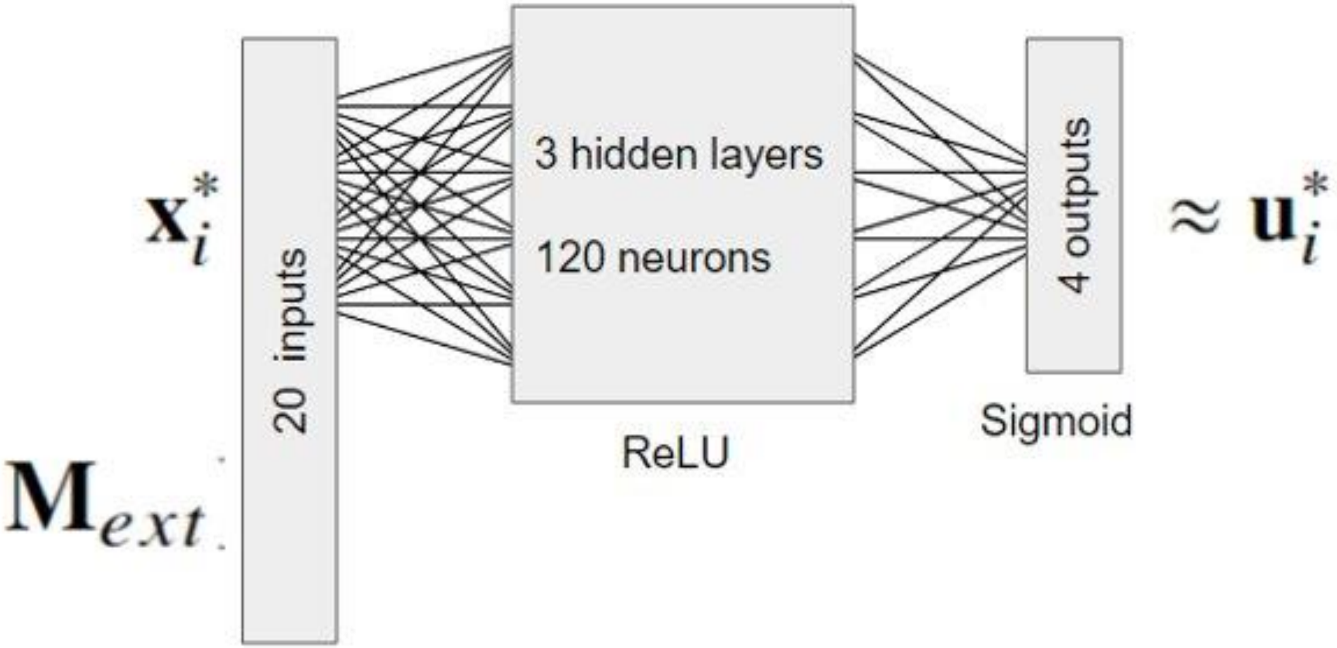
Results Master Thesis

2: Adaptive control strategy

- New Network
- 3 extra Inputs



Results Master Thesis

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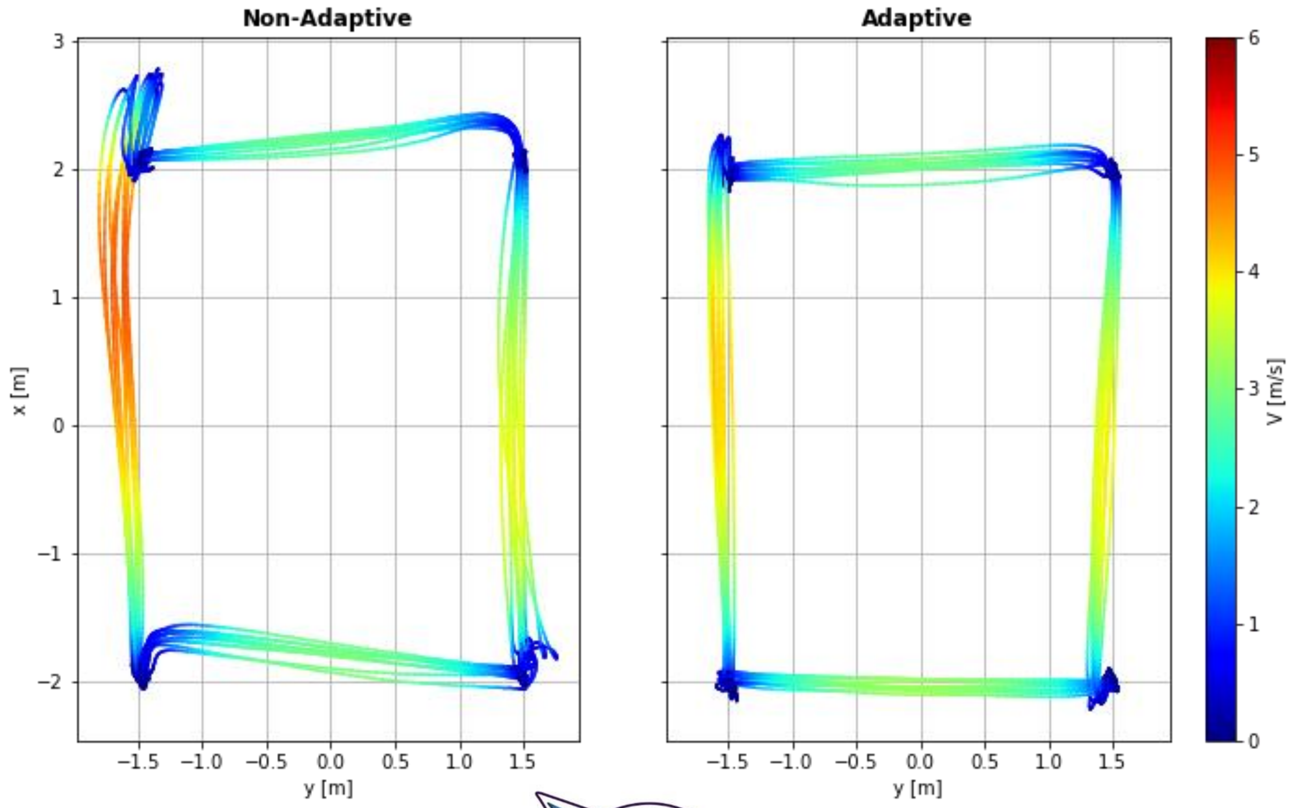

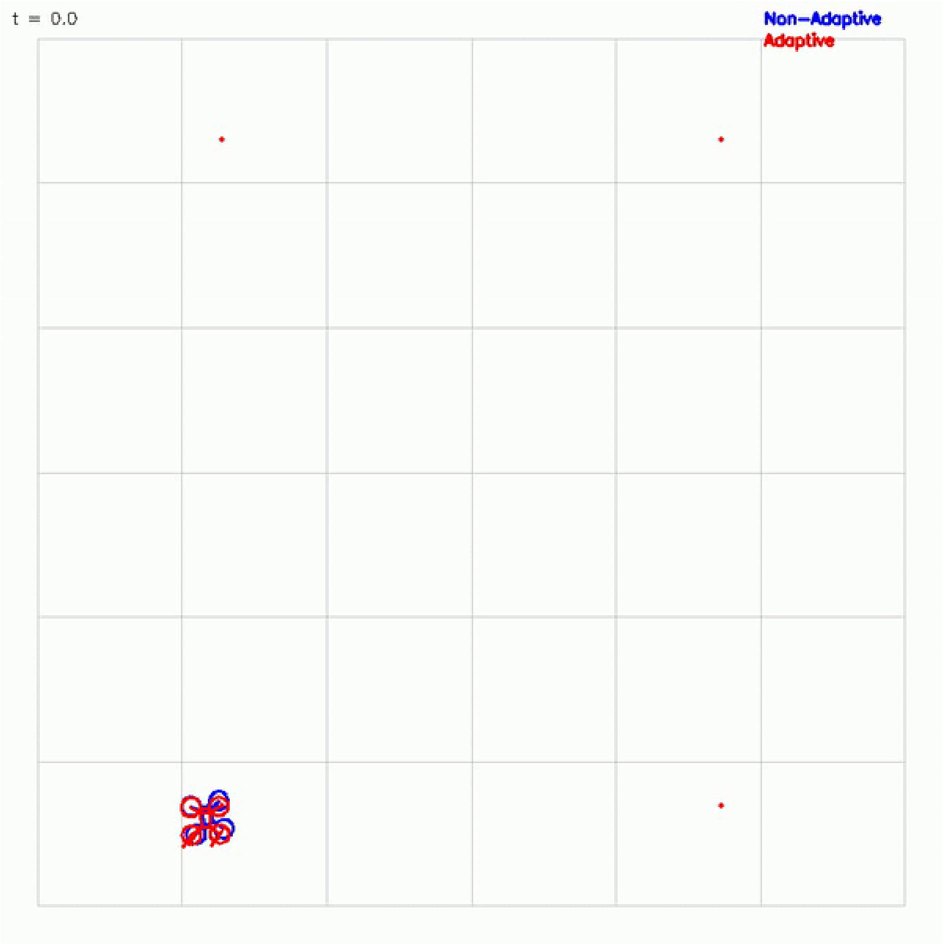

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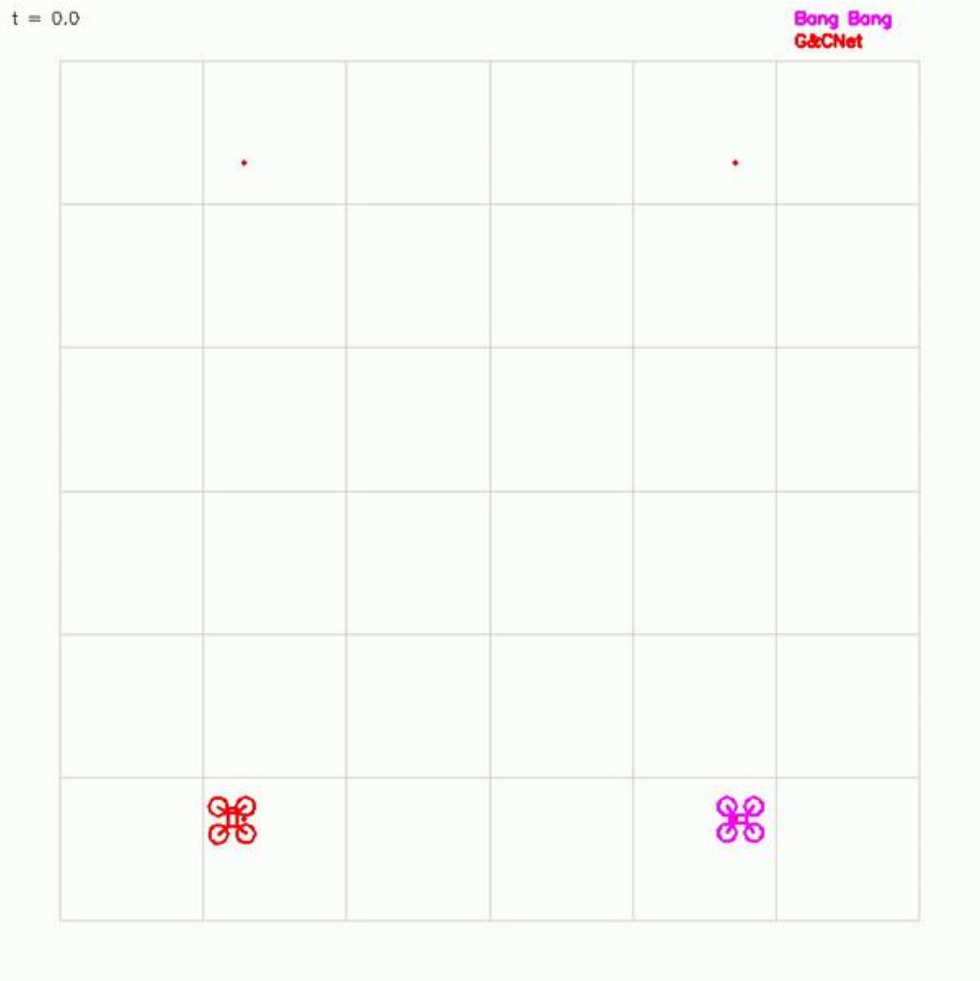
Results Master Thesis

3: Benchmark Flight performance



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Results Master Thesis

We have shown..

- **G&CNet** is feasible
- Significance of **unmodeled moments**
- Improved performance for **adaptive method**
- Capabilities of **high speed flight**

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Time-optimal quadrotor flight

Sebastien Origer

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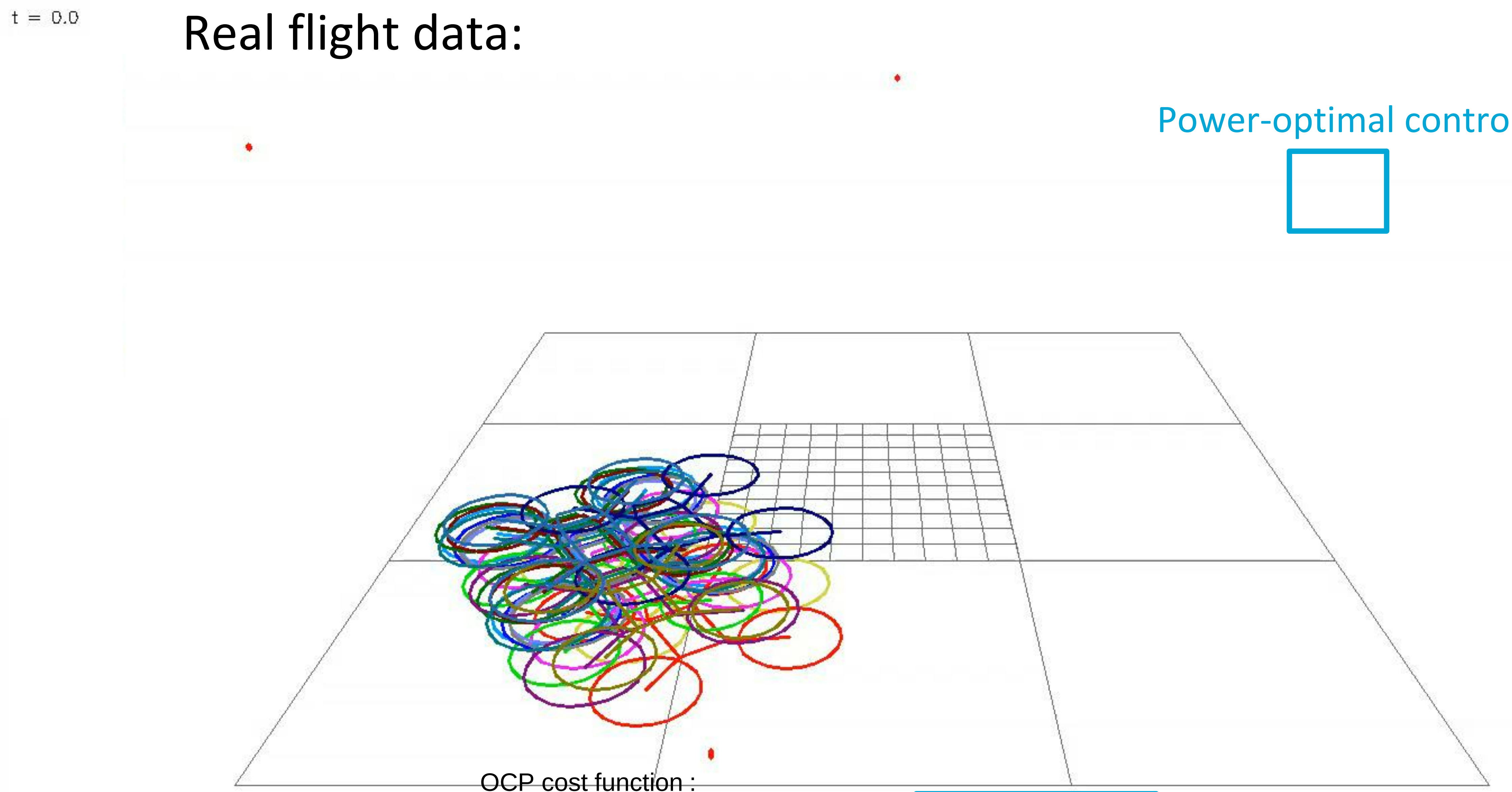
14 September, 2022

Real flight data:



Power-optimal control

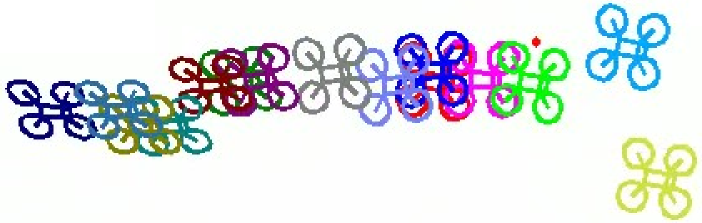
OCP cost function :

$$J\left(\epsilon, t_f, \boldsymbol{u}(t)\right) = (1-\epsilon)\, t_f + \epsilon \int_0^{t_f} \sum_{i=1}^{4} u_i(t)^2 \, dt$$

Time-optimal objective

Power-optimal objective

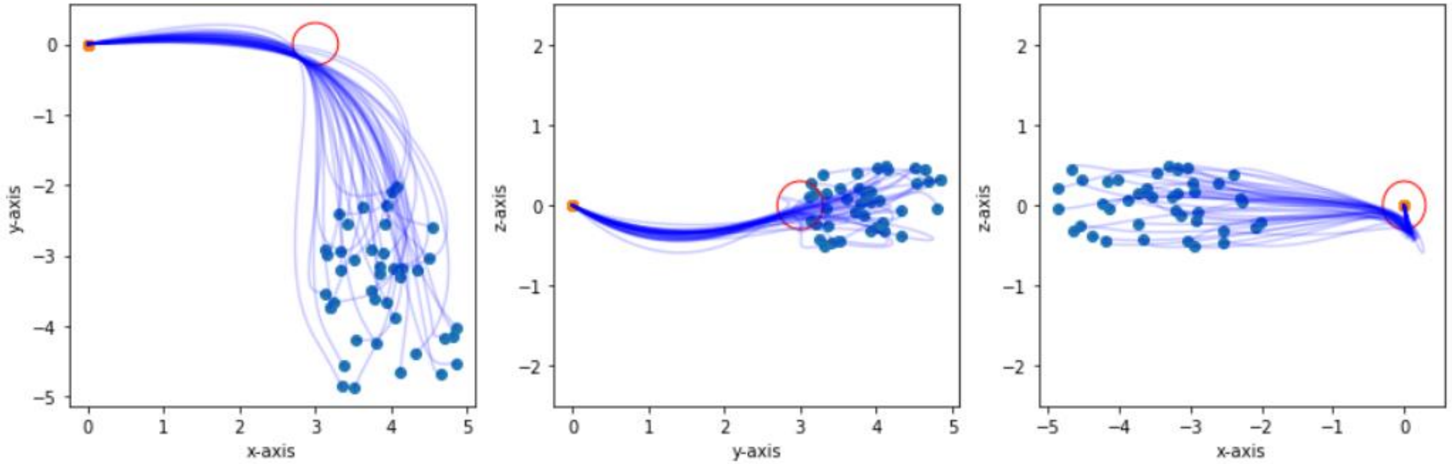
Current work



Does the reality gap reside in an inaccurate dynamics model or inappropriate OCP cost function?

Use of G&CNETs in combination with online system identification: adaptive solution

Experiments with different cost functions: 2 consecutive gates, add term for robustness



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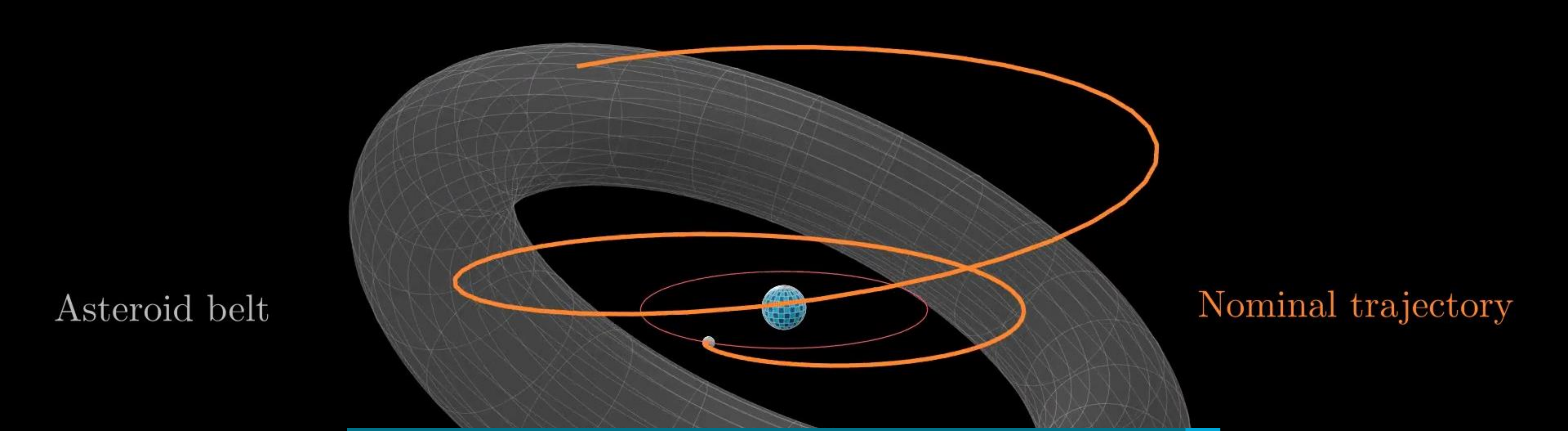

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Spacecraft guidance and control

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14 September, 2022

G&CNETs for spacecraft

✓ **Onboard use of GCNETs** is proven to work on quadrotors

- More difficult OCP (less deterministic than space dynamics)

✓ In case of space dynamics: **time to generate training dataset** can be severely reduced:

Simple ODEs

↓

Solve optimal control problem with Pontryagin's Maximum Principle

↓

Benefit from the 'Backward Generation of Optimal Samples' method

Animation illustrating the 'Backward Generation of Optimal Samples'

Based on:

Neural representation of a time optimal, constant acceleration rendezvous

Dario Izzo, Sebastien Origer

Results G&CNETS (Simulation)

9 different nominal trajectories (Axis unit is AU)

↓

Applied Backward Generation of Optimal Samples

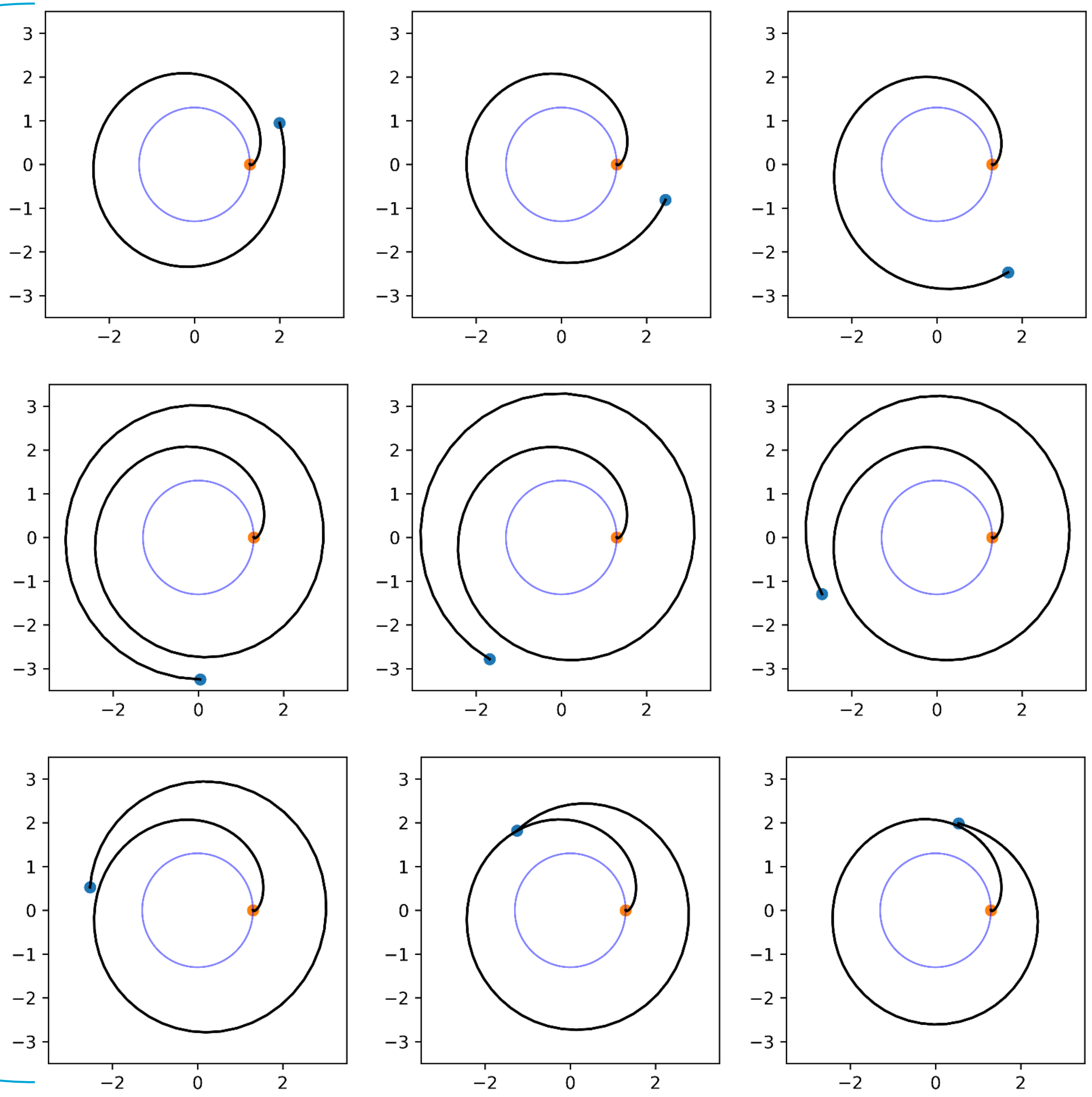
↓

Trained G&CNETs

↓

Validated networks in simulation:

Final position error	< 500,000 km
Final velocity error	< 100 m/s



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Networks can also learn the value function

$\mathcal{N}(\mathbf{r}, \mathbf{v})$ = Tof (Time of Flight)

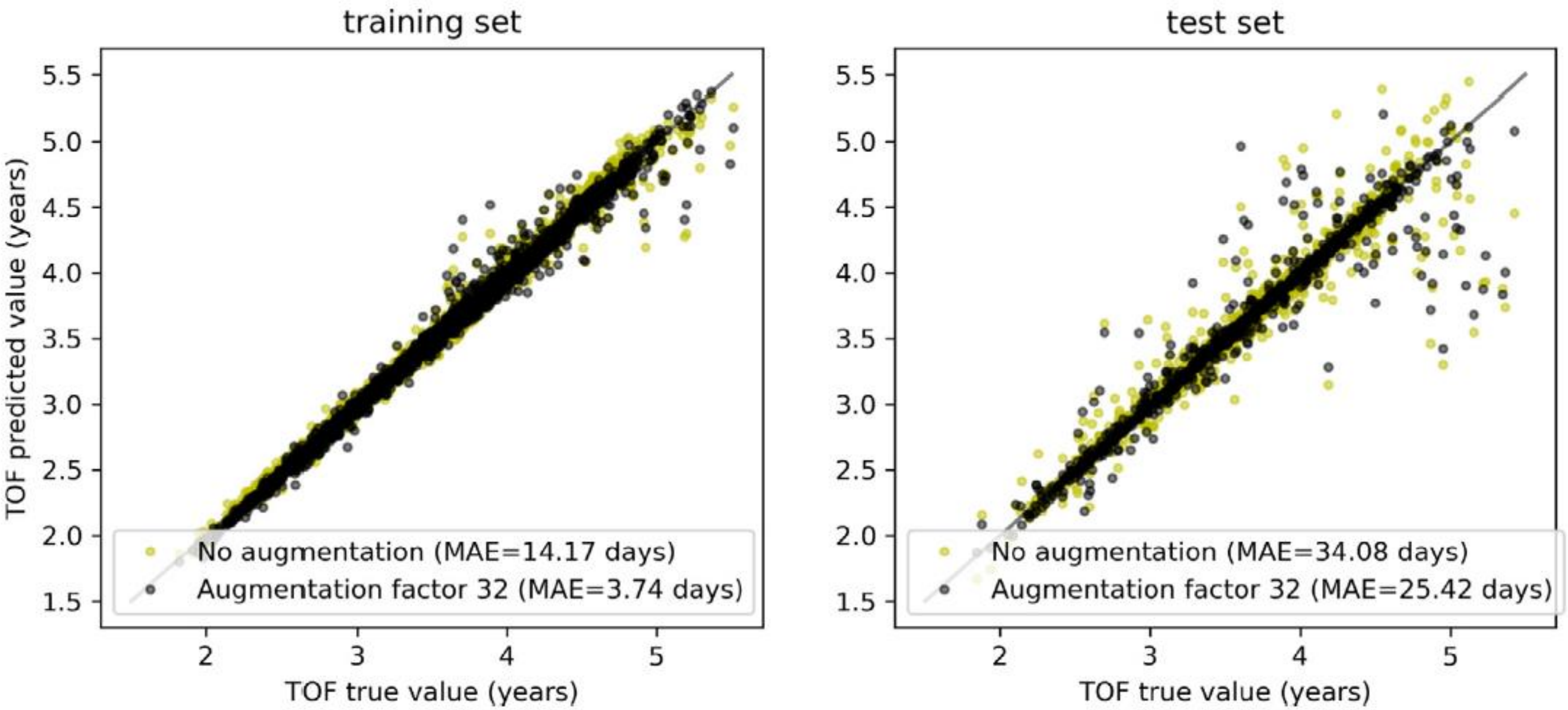

Fig. 6. Error on the training/test set.

→ Useful for preliminary mission design

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Where did we start? Where are we now?

- Started:
  - GCNETs only in simulation
- Now:
  - G&CNETs proven to work onboard quadcopters and can be made adaptive
  - G&CNETs are a solution to autonomous onboard guidance and control which requires low computational cost during inference
  - Efficient data augmentation technique for complex low-thrust interplanetary missions (training datasets were generated in under a minute)
  - G&CNETs meet operational requirements for interplanetary missions in terms of accuracy
  - Methodology can also be used to train networks to predict the value function, which is of interest for preliminary mission designs
- Future:
  - Time-optimal quadcopter flight using G&CNETs
  - Study asymptotic behaviour of G&CNETs

Thank you for your attention

Robin Ferede & Sebastien Origer

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