Self-positioning of a team of flying cameras

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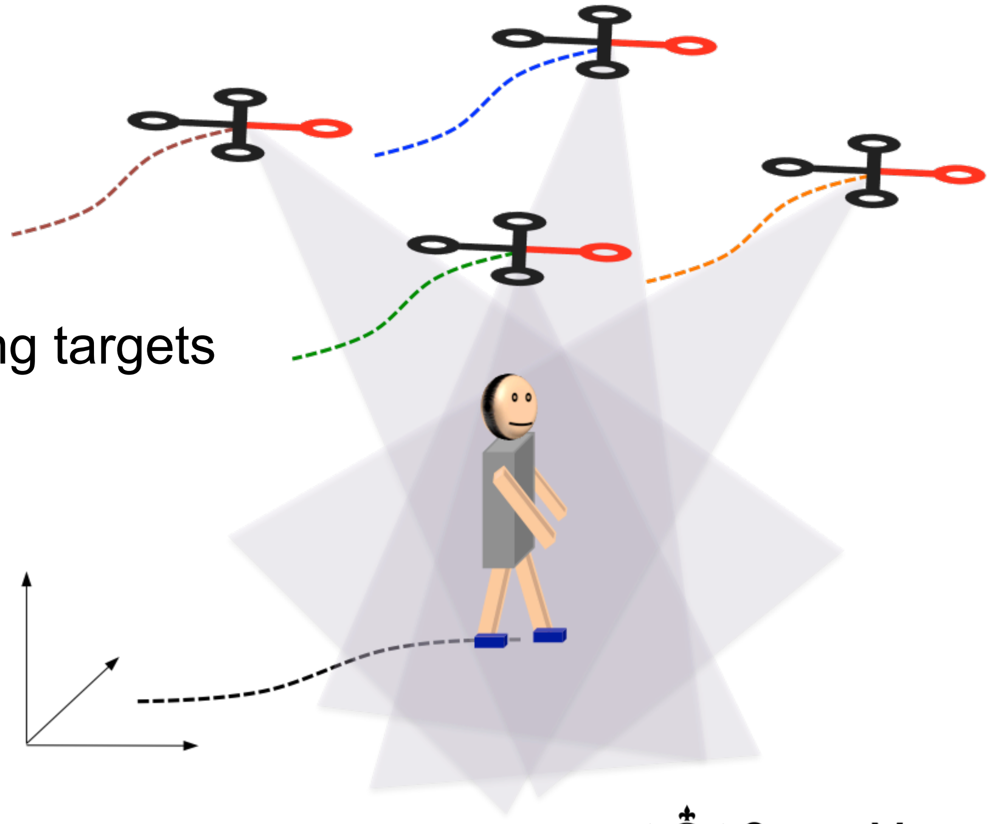
Introduction

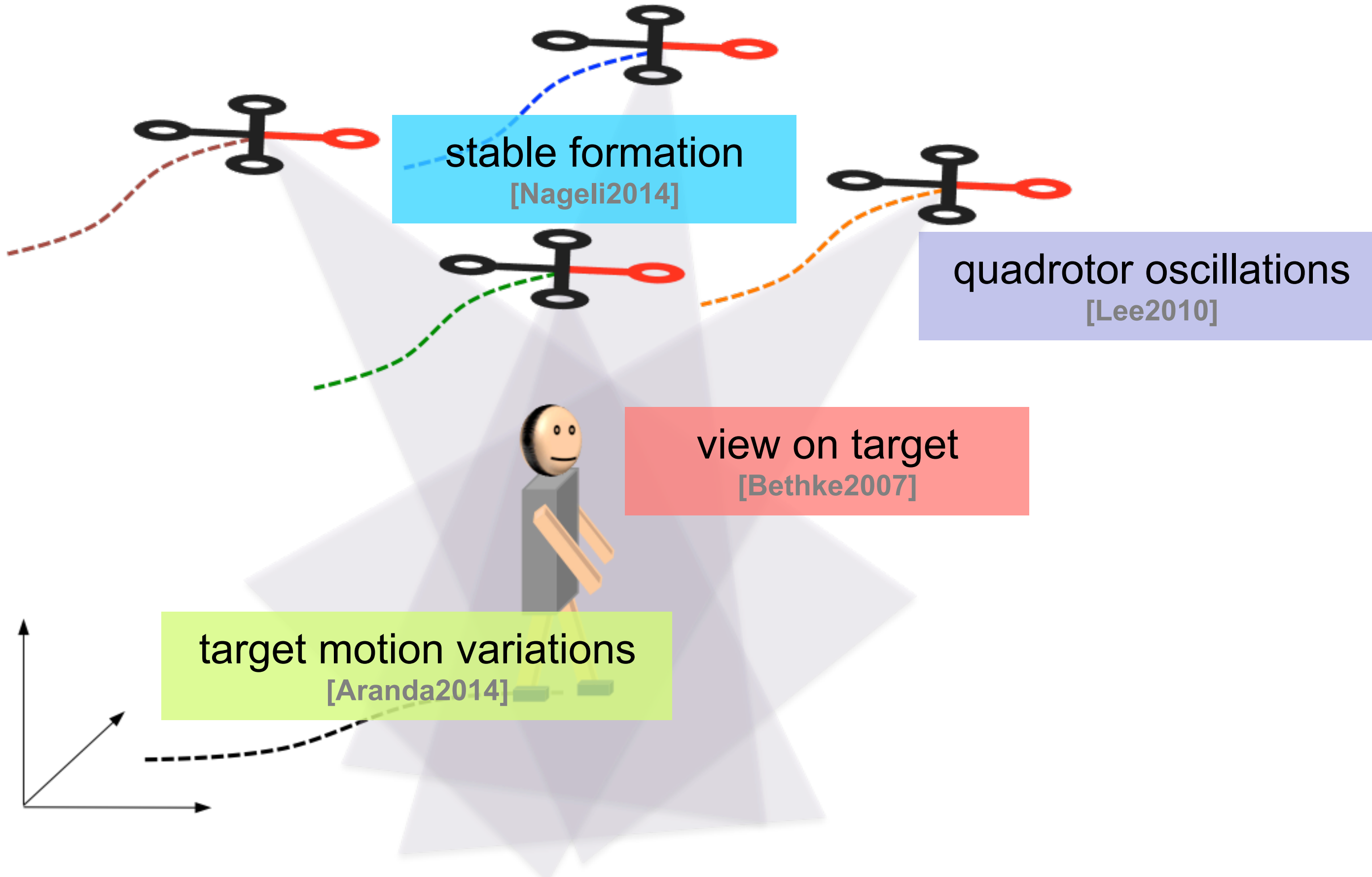
- Goal: self-position a team of camera-equipped quadrotors using local decisions

  (*flying cameras*)

- Why?
  - Filming/monitoring of moving targets
    - choose best view
    - 3D target view
  - Robustness to occlusions



Challenges



- T. Nageli *et al.*, “Environment-independent formation flight for micro aerial vehicles,” Proc. of International Conference on Intelligent Robots and Systems, Chicago, IL, USA, Sep. 2014
- T. Lee *et al.*, “Geometric tracking control of a quadrotor UAV on SO(3),” Proc. of International Conference on Robotics and Automation, Atlanta, GA, USA, Dec. 2010
- B. Bethke et al., “Cooperative vision based estimation and tracking using multiple UAVs,” in Proc. of International Conference on Cooperative Control and Optimization, Gainesville, FL, USA, Jan. 2007
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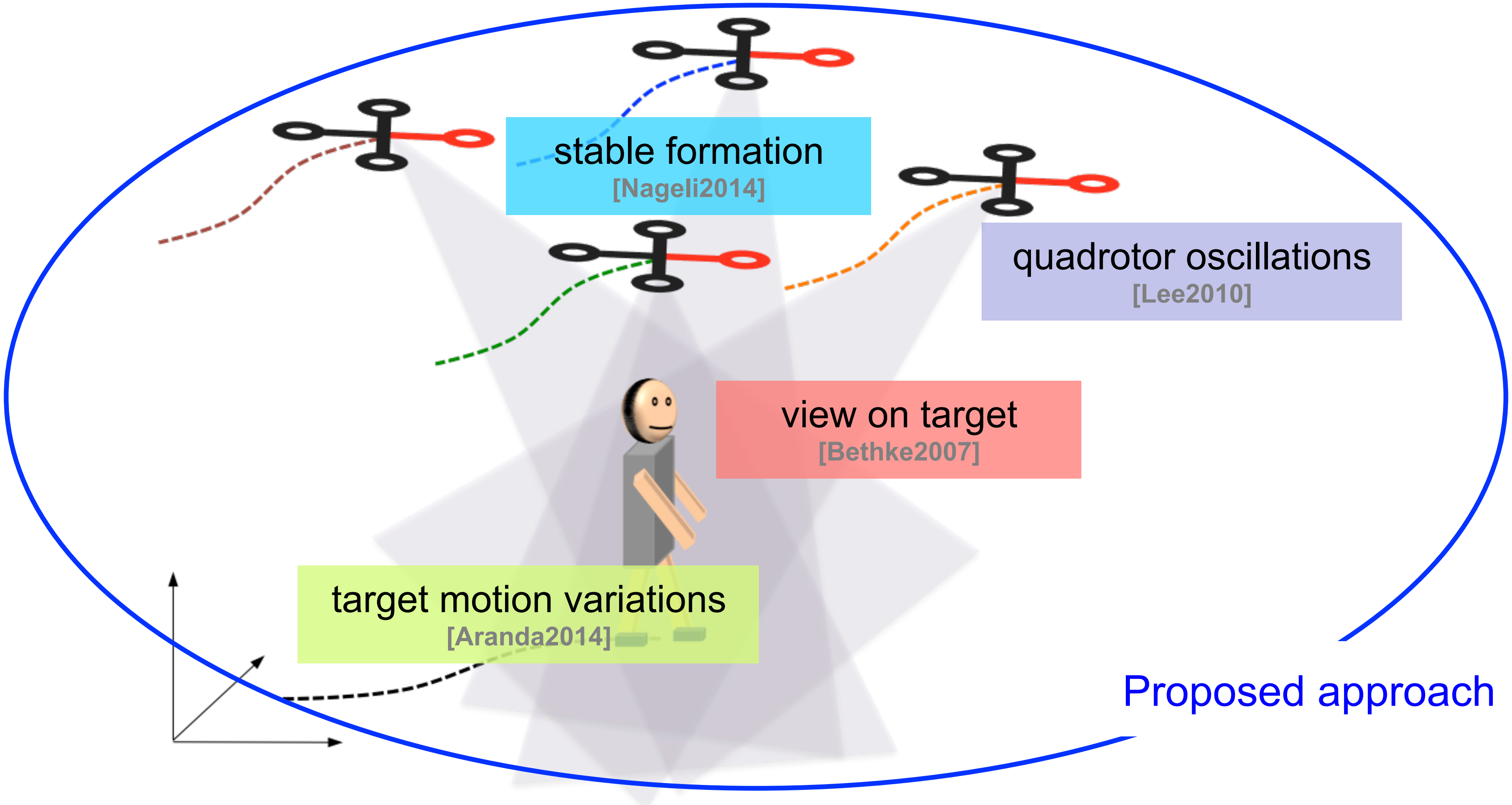

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Problem formulation

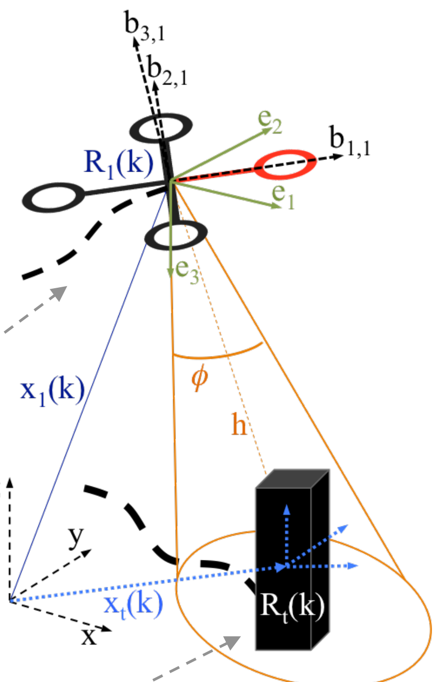
- Team of flying cameras $M(k) = \{q_i(k)\}_{i=1}^{N}$

- Flying camera $q_i(k) = (x_i(k), R_i(k))$
  - position $x_i(k) \in \mathbb{R}^3$
  - attitude (orientation) $R_i(k) \in SO(3)$

- Objectives
  - reach goal locations on target

    $$G(k) = \{g_i(k)\}_{i=1}^{N} \qquad g_i(k) \in \mathbb{R}^3$$

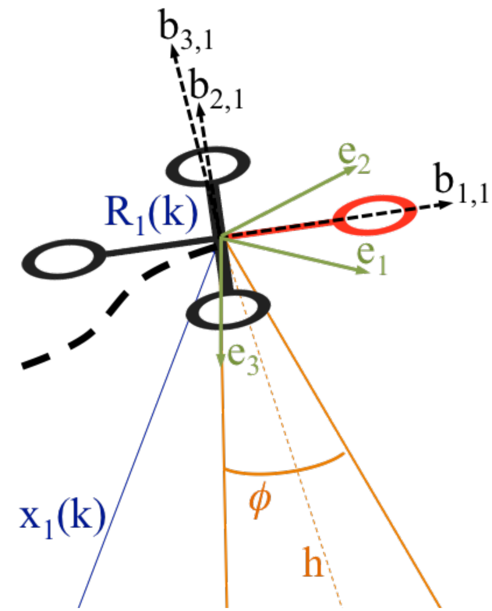
  - achieve desired views
    - target fully included in fields of view



flying cameras know (locally) target position

Self-positioning and collision avoidance

- Flight controller of a flying camera
  - Input:
    - desired trajectory point $x_{d,i}(k) \in \mathbb{R}^3$
    - desired first-body direction $b_{1_{d,i}}(k) \in \mathbb{R}^3$
  - Output
    - position and attitude $(x_i(k), R_i(k))$



- Force based model affects desired dynamics ($x_{d,i}(k), b_{1_{d,i}}(k)$)

attractive force towards the goal

$$F_{m,i}(k) = F_{g,i}(k) + F_{r,i}(k)$$

repulsive force from neighbours

Target-based positioning

- Each flying camera locally computes
  - goal position

$$
\begin{aligned}
g_{l,i}(k) &= R_t(k)\, g_i(k) \\
&= R_t(k)\, (x_t(k) + x_{f,i})
\end{aligned}
$$

fixed goal location w.r.t. $x_t(k)$

  - displacement

$$
v_{l,i}(k) = \beta(k)\, (R_i(k)\, R_t^{-1}(k)\, g_{l,i}(k) - R_i(k)\, x_i(k))
$$

$$
\beta(k) = \begin{cases} 1 - \frac{\tau - k}{\tau - k_0} & \text{if } k \in [0, \tau] \\ 1 & \text{if } k \in (\tau, K] \end{cases}
$$

deadline to reach goal position

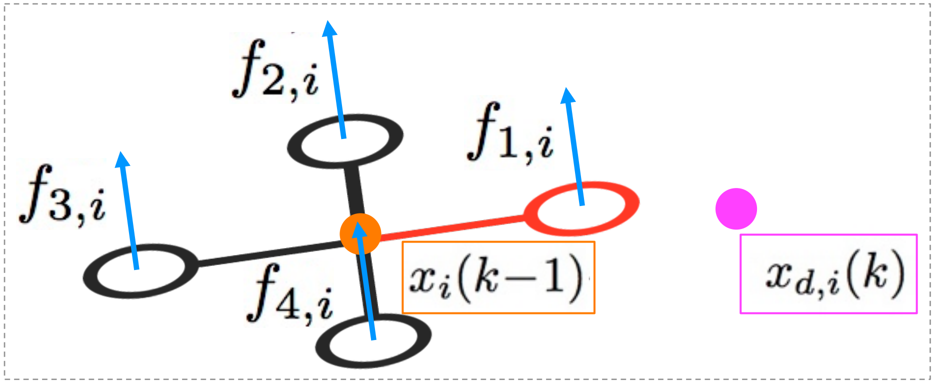
Flight dynamics model [Lee2010]

- Desired trajectory point and first-body direction

$$x_{d,i}(k) = x_i(k-1) + \left(R_i(k)\, v_{l,i}(k) + \frac{F_{m,i}(k)}{m_i} dk \right) dk$$

flying camera mass

$$b_{1_{d},i}(k) = x_{d,i}(k) - x_i(k-1)$$



- Given $x_{d,i}(k)$

$f_i = \sum_{n=1}^{4} f_{n,i}$ and $b_{3_{d},i}(k)$ are computed to stabilise translational dynamics

T. Lee *et al.*, "Geometric tracking control of a quadrotor UAV on SO(3)," Proc. of International Conference on Robotics and Automation, Atlanta, GA, USA, Dec. 2010, pp. 5420– 5425.

Simulation results

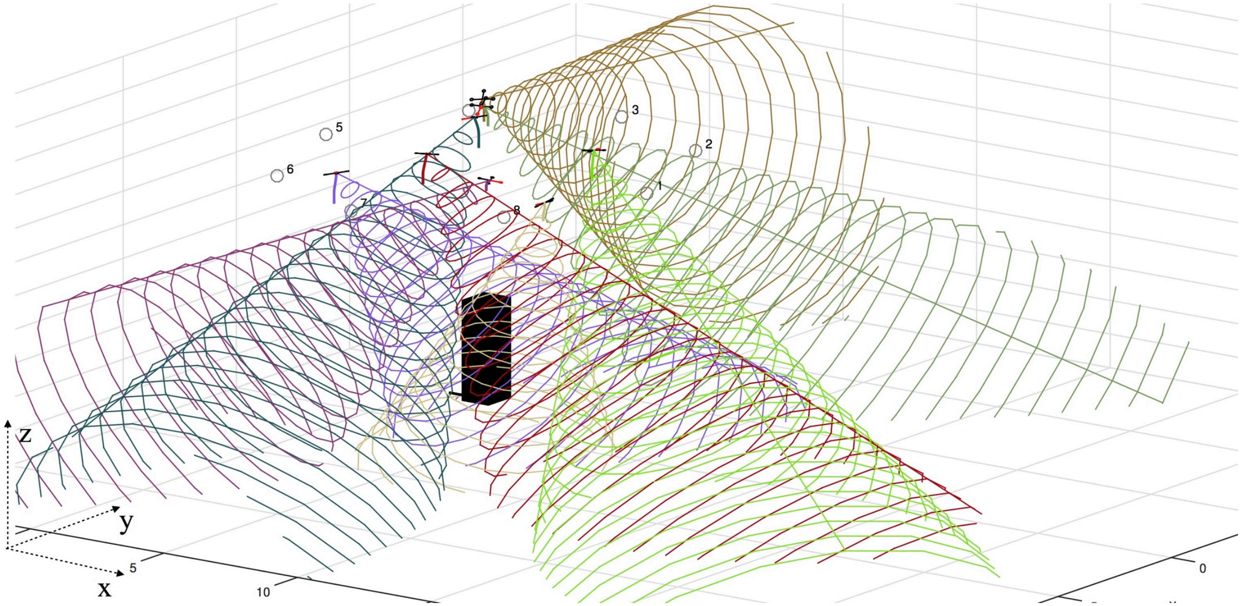
- Randomly initialised starting positions
- 100 runs per experiment
- Target trajectories
  - straight-line $v_{tar} = (2 \cdot dk, 0, 0)^T$
  - sinusoidal $v_{tar} = (2 \cdot dk, 0.08 \cdot cos(\frac{2}{5}\pi k), 0)^T$
- Wireframe target (8 vertices)
  - evaluate → mean (standard deviation) vertices viewed over time

TABLE I. DESIRED (GOAL) LOCATIONS WITH RESPECT TO THE MOVING TARGET LOCATION. GOAL LOCATIONS ARE GIVEN AS PRIOR TO FLYING CAMERAS IN OUR EXPERIMENTS. KEY - FC: FLYING CAMERAS; N: NUMBER OF FLYING CAMERAS; L: RADIUS OF THE FORMATION; H: FLIGHT ALTITUDE.

$$x_{f,i} = (L \cdot cos((i-1)\frac{\pi}{N/2}, L \cdot sin((i-1)\frac{\pi}{N/2}, H)^T$$

Name	Parameters
FC-6	$N = 6, L = 6, H = 7$
FC-8	$N = 8, L = 6, H = 7$
FC-10	$N = 10, L = 6, H = 7$
FC-12	$N = 12, L = 6, H = 7$

Straight-line trajectory (N=6)

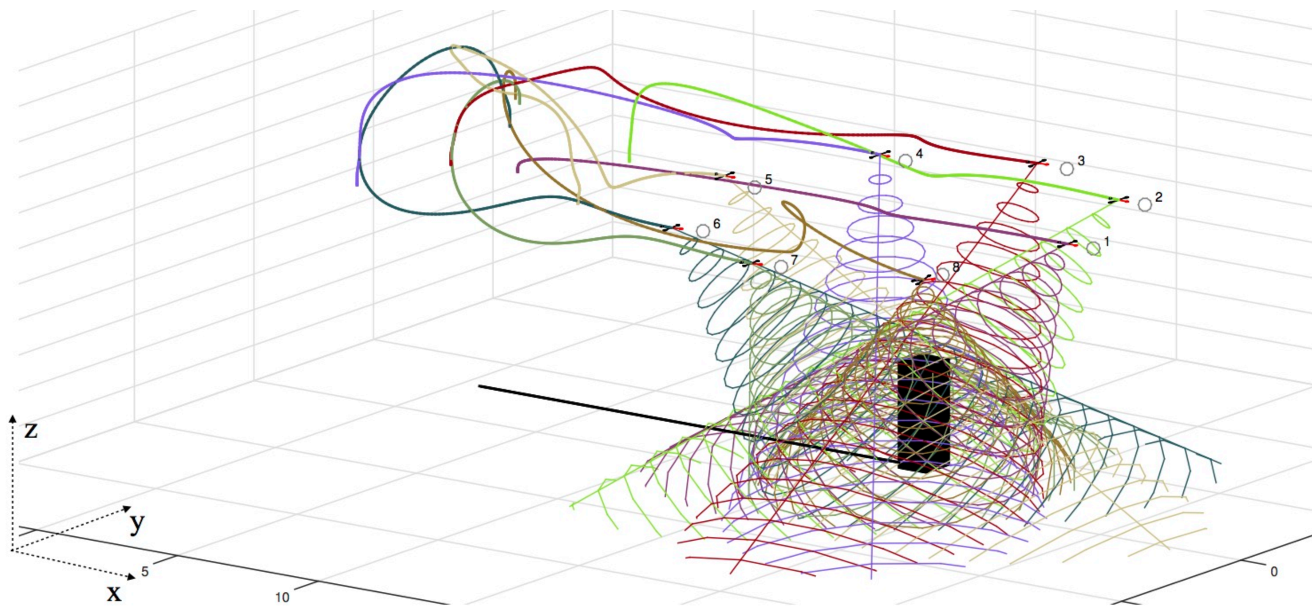


Random initialisation

- views not on target
- transition time to achieve stabilitsation

Desired view achieved

- flying cameras in formation
- all views on target



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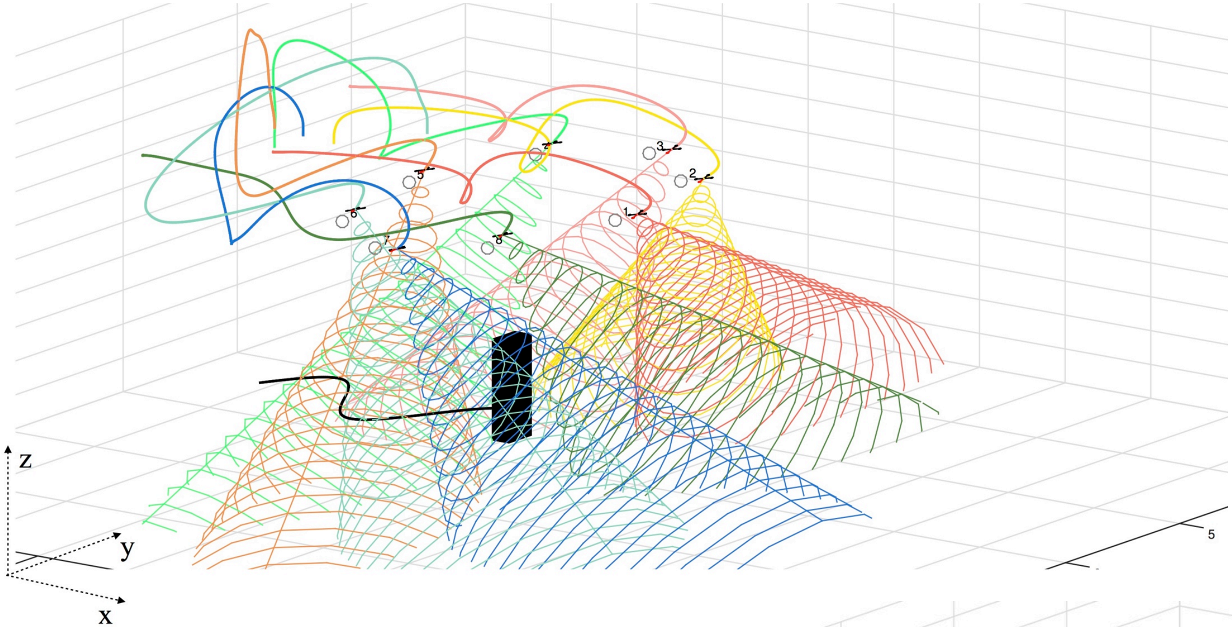
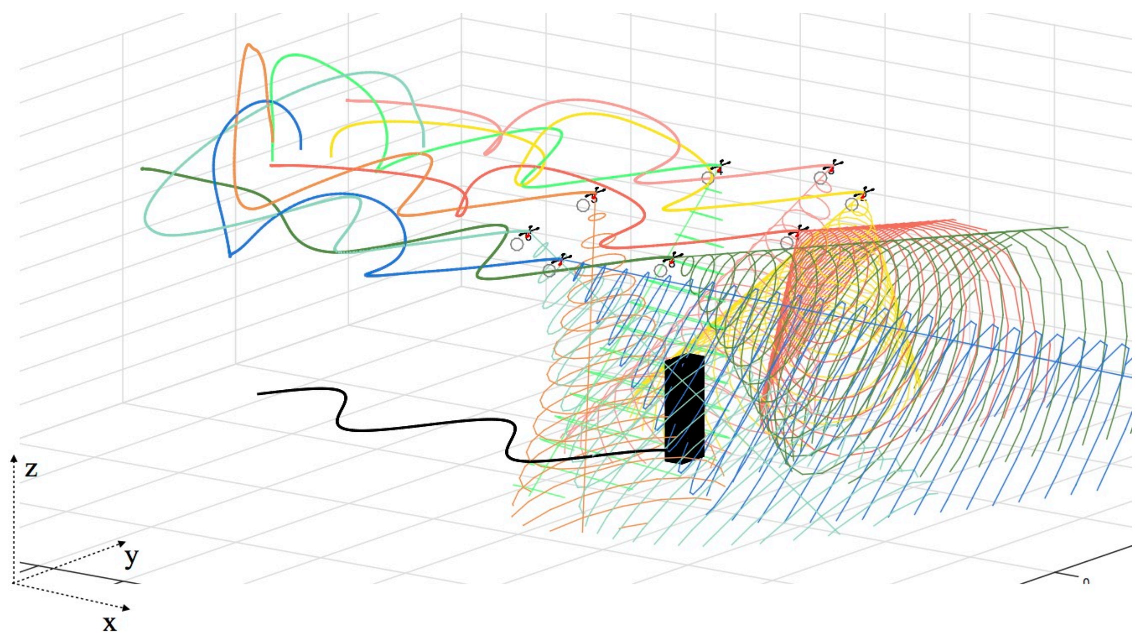
Sinusoidal trajectory (N=6)



- Target dynamics hinder stable target view
- Desired view not achieved



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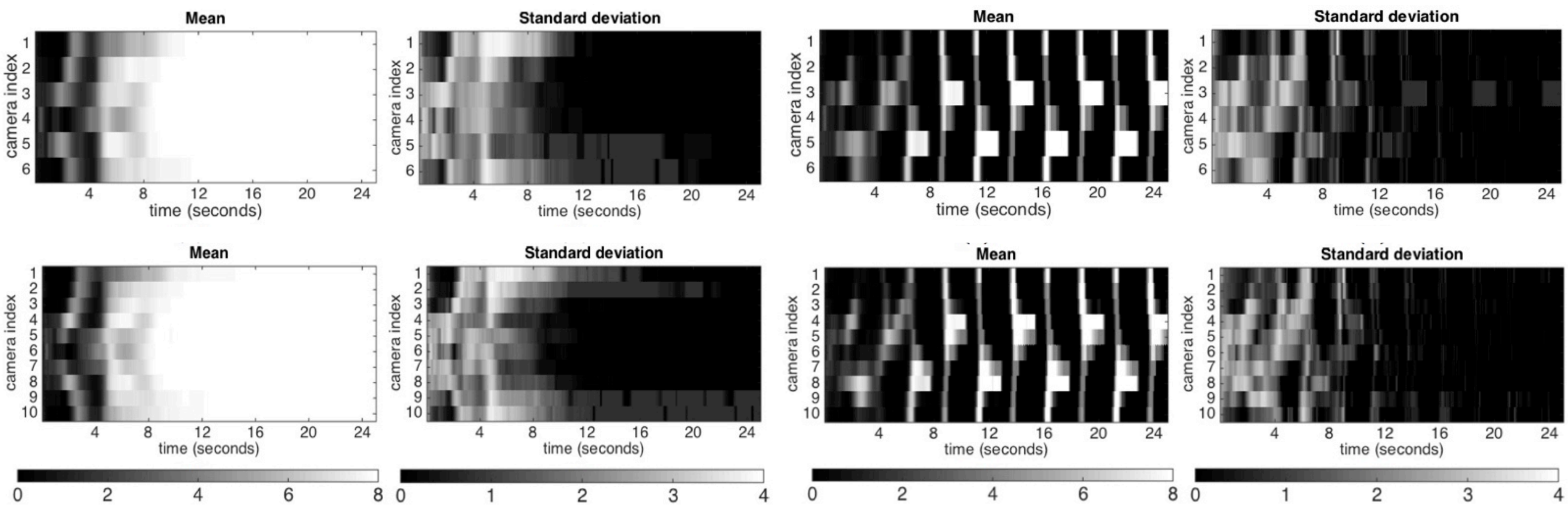
Camera view performance

- Examples with N = 6, 10
- Front flying cameras
  - (straight-line trajectory) reach desired view slower
  - (sinusoidal trajectory) barely view the target during the chase

straight-line trajectory | sinusoidal trajectory



Conclusions

- Desired view of the target
  - discontinuous when the target changes direction
  - affected by flying camera oscillations
  - delayed with the front flying cameras

- Future work
  - Target motion prediction will help stable quadrotor manouevres