Formations of flying cameras to film a moving target

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Reference papers

- F. Poiesi and A. Cavallaro, “**Distributed vision-based flying cameras to film a moving target**,” IEEE Proc. of IROS, Hamburg, GE, Sep 2015

- F. Poiesi and A. Cavallaro, “**Self-positioning of a team of flying smart cameras**,” IEEE Proc. of ISSNIP, Singapore, Apr 2015

Target filming with a flying camera

lily.camera

HEXO+

LILY

3DR

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Flying camera positioning

Transmitter

Manual control of the position

↓

GPS based positioning

The user sets the desired point of view

The flying camera follows the user while maintaining its relative position

Target filming with **multiple** flying cameras

filming from
multiple points of
view

the flying cameras follow the target while maintaining their relative positions (formation)

local processing to reduce communication costs

distributed decision making

- scalable framework
- rubust to failures

Challenges

- Stable formation
  - maintain relative distances
- Flying camera oscillations
  - jerky recordings will not be pleasant to watch
- Maintain view on target
  - centered in the field of view
- Target motion variations
  - smooth steering manoeuvers (do not overreact)

Definitions

set of flying cameras

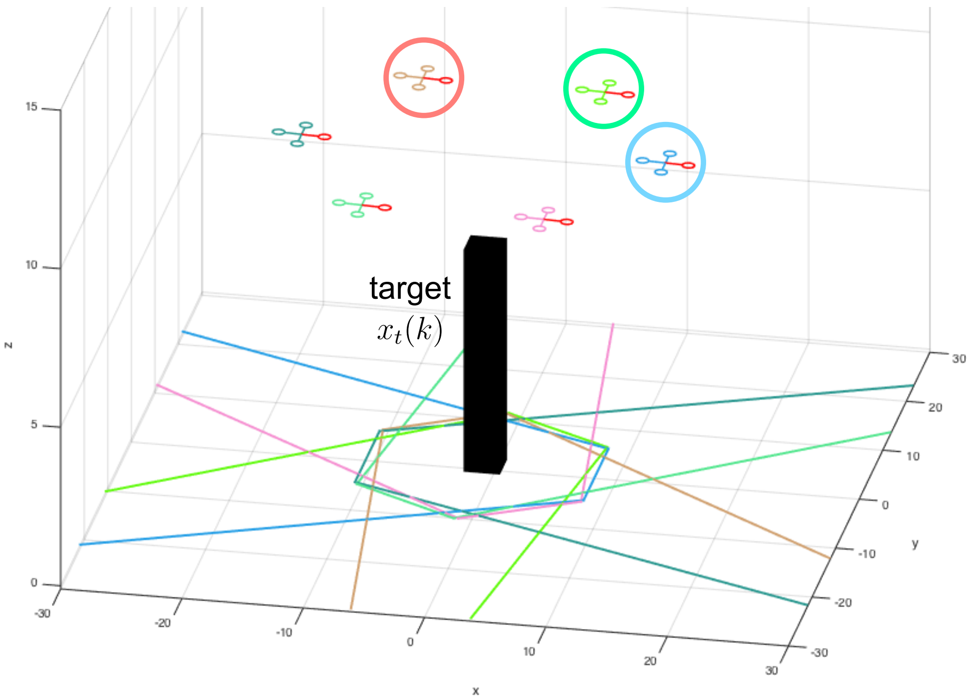
$$\mathcal{C}(k) = \{C_i(k)\}_{i=1}^{N}$$

position $x_i(k) \in \mathbb{R}^3$

$$C_i(k) = (x_i(k), R_i(k))$$

attitude (orientation)

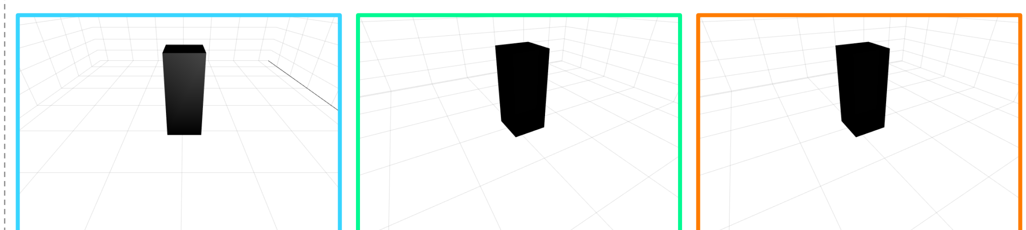
$R_i(k) \in SO(3)$



On-board camera

$$R_{c,i} \in SO(3)$$

fixed orientation



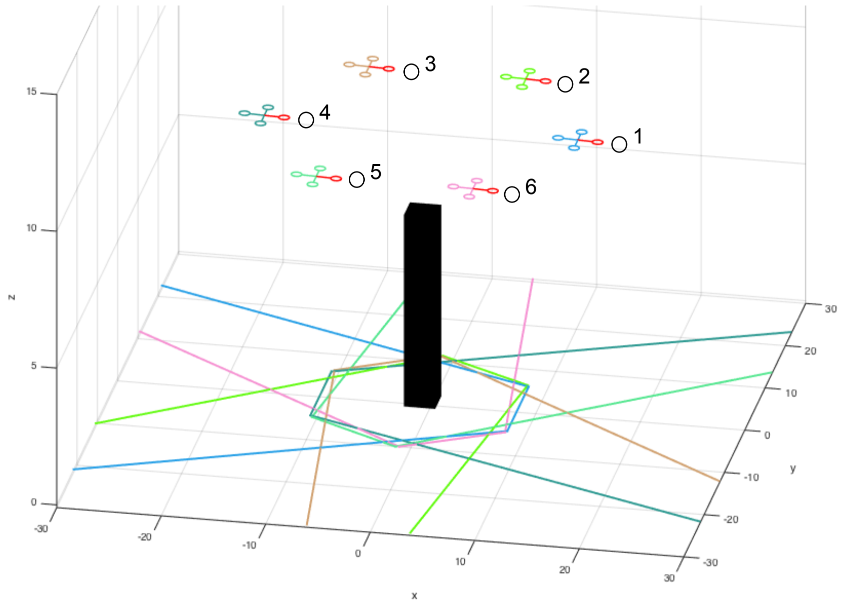
Examples of flying camera views

Objective

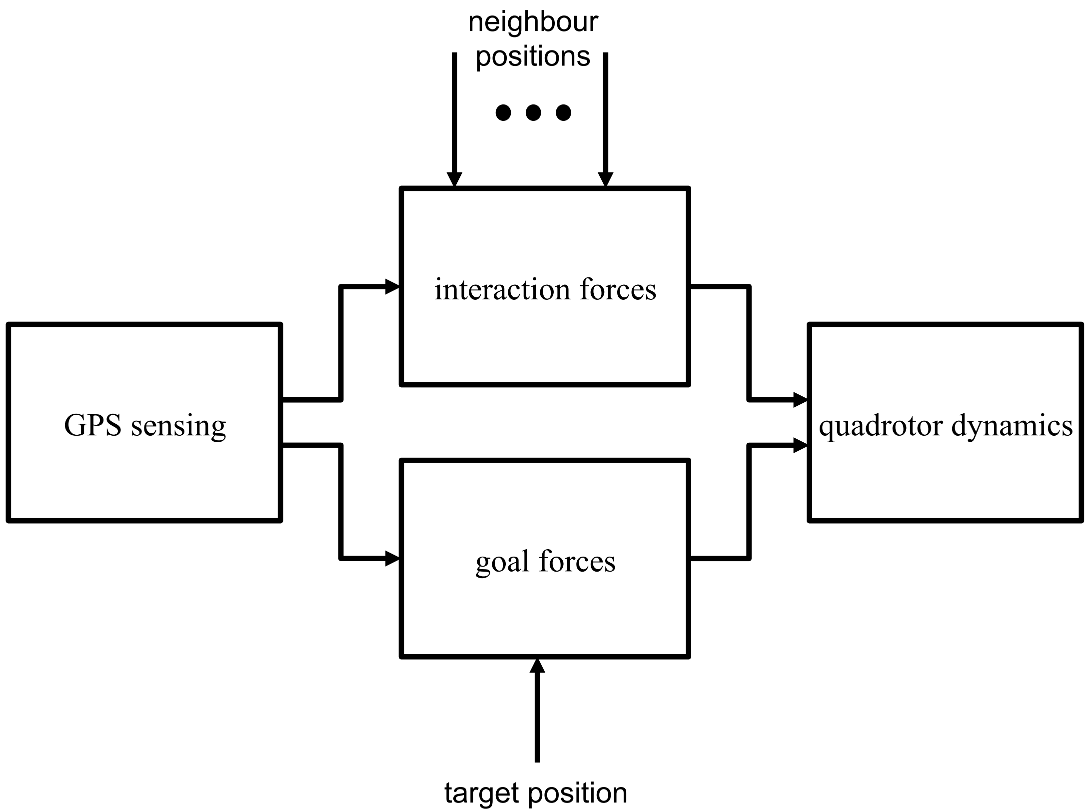
- Reach and follow goal positions on target

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

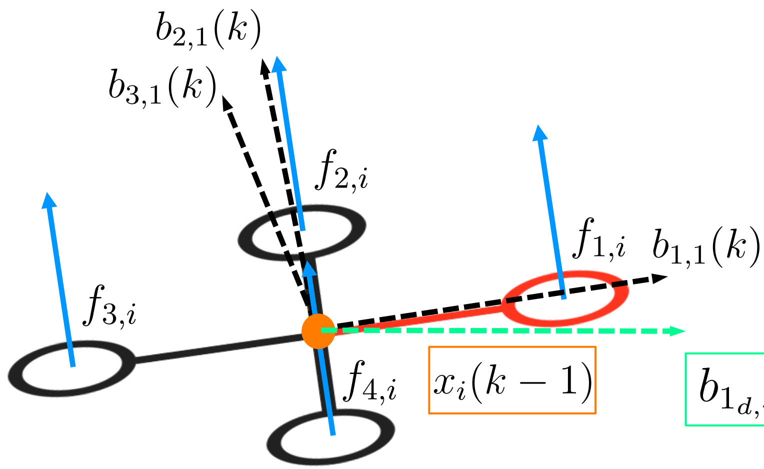
- Achieve desired views
  – target fully included in fields of view



Force-based framework model



Flying camera controller [Lee2010]



Input

$x_{d,i}(k)$ desired trajectory point

$b_{1_{d,i}}(k)$ desired first body direction

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

$$\updownarrow$$

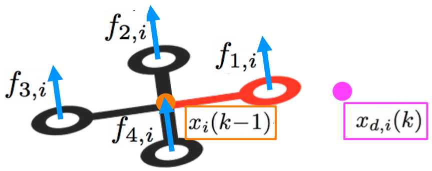
- Given $x_{d,i}(k)$ and $b_{1_{d,i}}(k)$ $\rightarrow$ $f_i = \sum_{n=1}^{4} f_{n,i}$, $b_{3_{d,i}}(k)$ $\rightarrow$ $(x_i(k), R_i(k))$

Compute this!
- neighbours' positions
- target position

*stable translational dynamics

- T. Lee *et al.*, "Geometric tracking control of a quadrotor UAV on SO(3)," in ICRA 2010

Desired trajectory point



attractive force towards the goal

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

repulsive force from neighbours

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

flying camera mass

weighting function

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

$$g_{l,i}(k) = R_t(k)\, g_i(k) = R_t(k)\left(x_t(k) + x_{f,i}\right)$$

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

Simulation results

- Objective: maintain target centred in fields of view

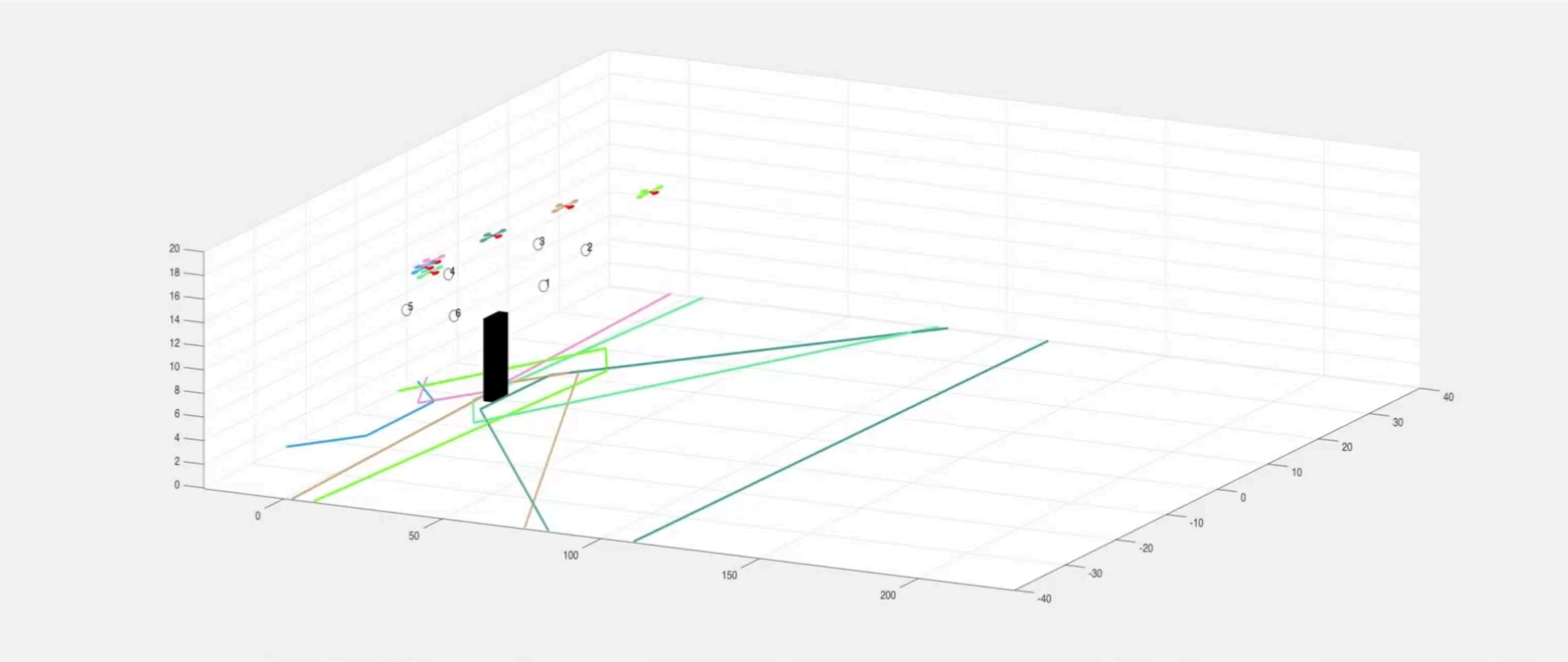
- Randomly initialised starting positions
- Goal positions

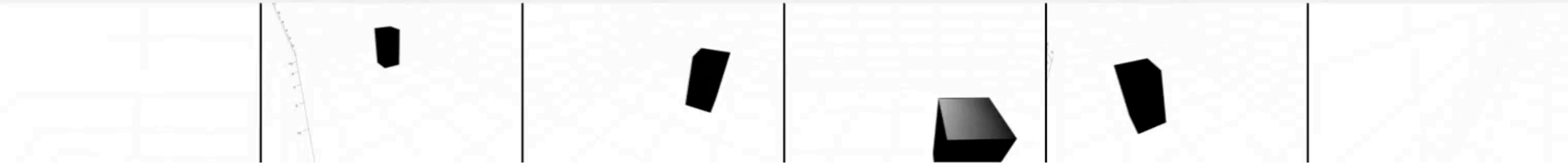
$$x_{f,i} = (\underset{\overset{\updownarrow}{15}}{L} \cdot cos((i-1)\frac{\pi}{N/2}), L \cdot sin((i-1)\frac{\pi}{N/2}), \underset{\overset{\updownarrow}{10}}{H})^T$$

- Example with a 6-flying-camera formation (hexagon)

- Target trajectories
  - without direction changes
  - with direction changes

Without direction changes





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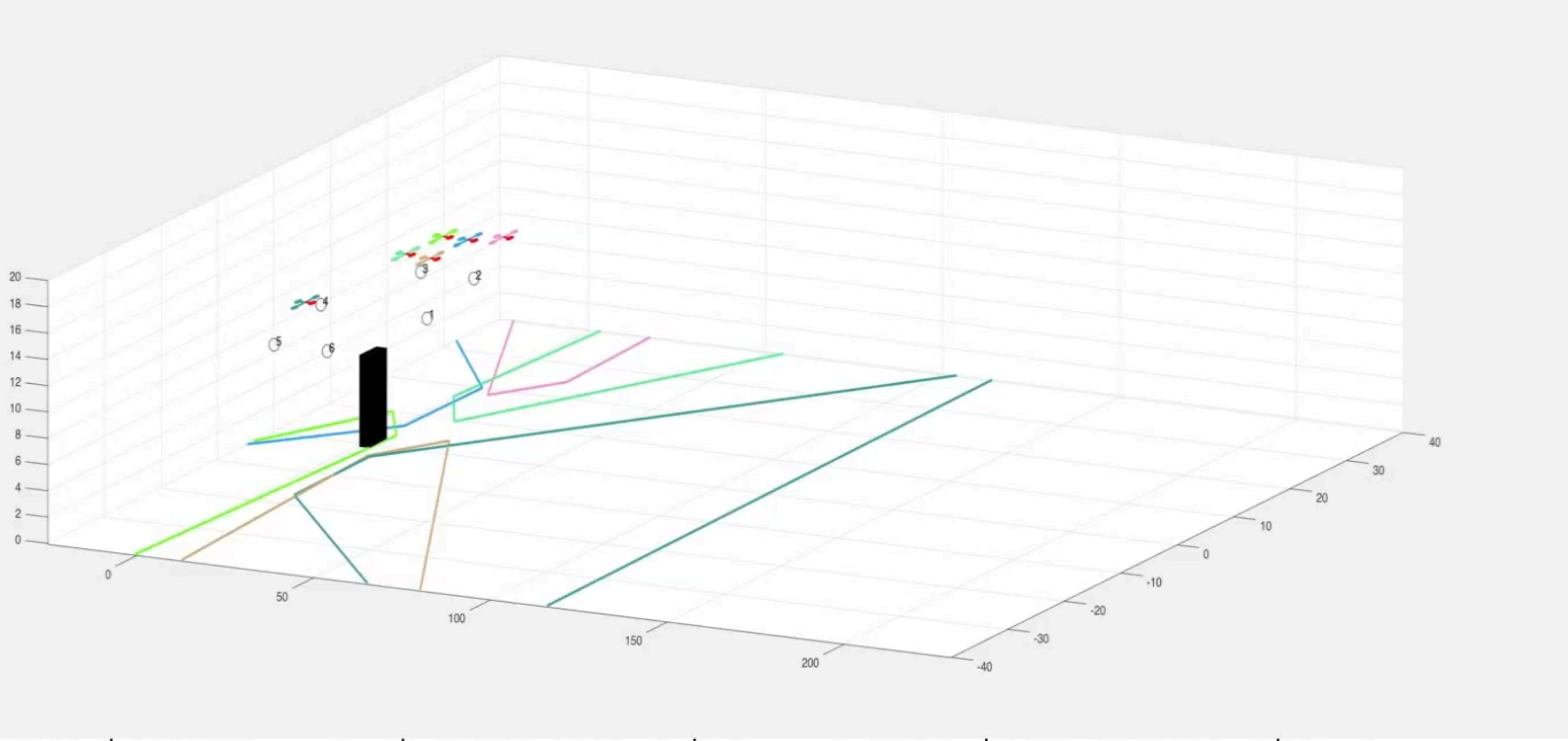
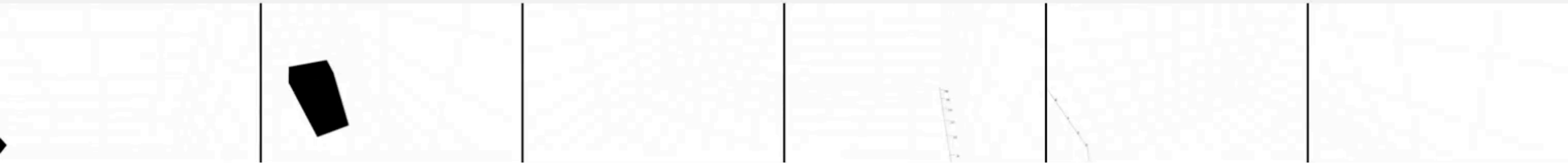
With direction changes





Discussion

GPS-based positioning only

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robust to follow the target

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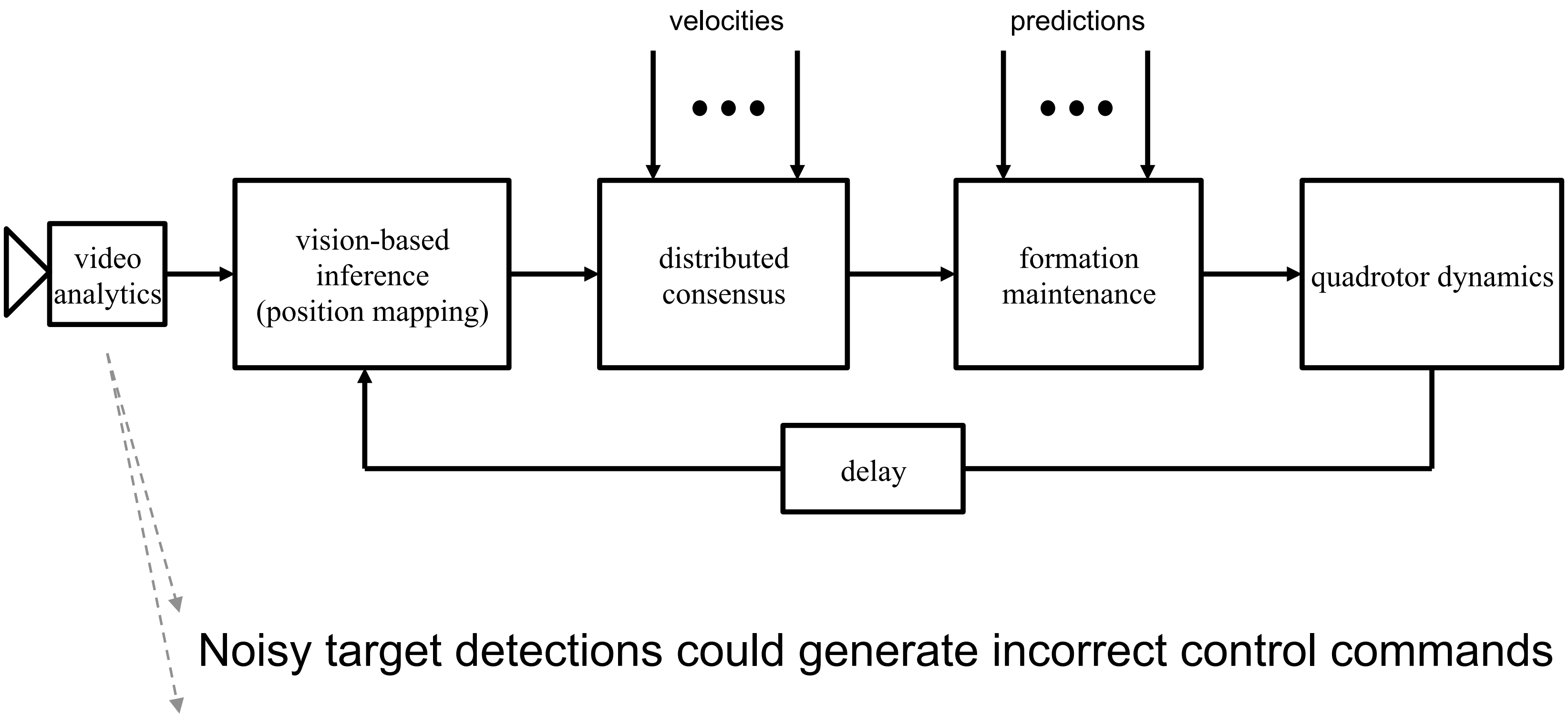
when GPS signal is available and strong

↓

no knowledge about target inclusion in fields of view

How do we follow a target without GPS?

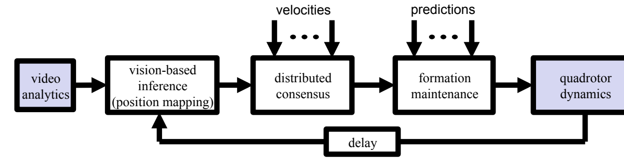
- Use smart vision!

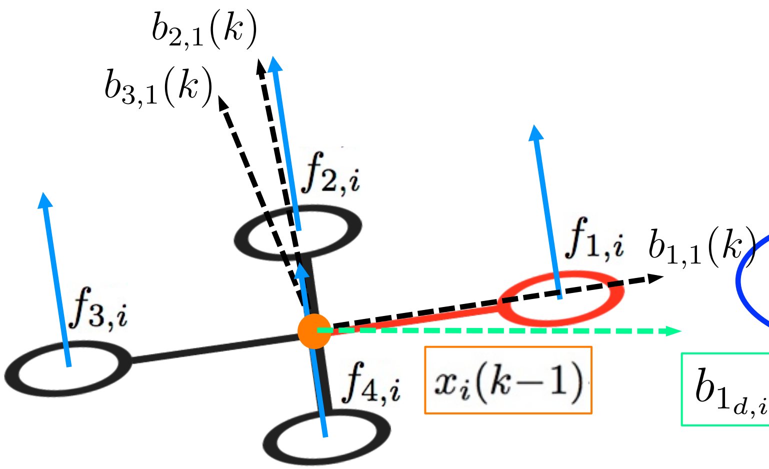


Noisy target detections could generate incorrect control commands

Target could go outiside the fields of view

Flying camera controller [Lee2010]

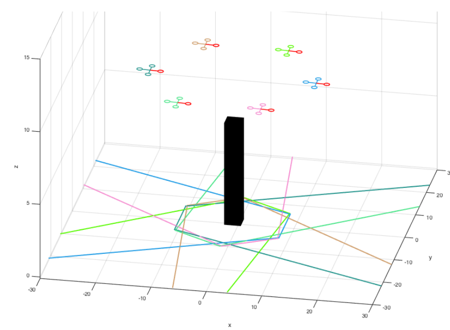




Input

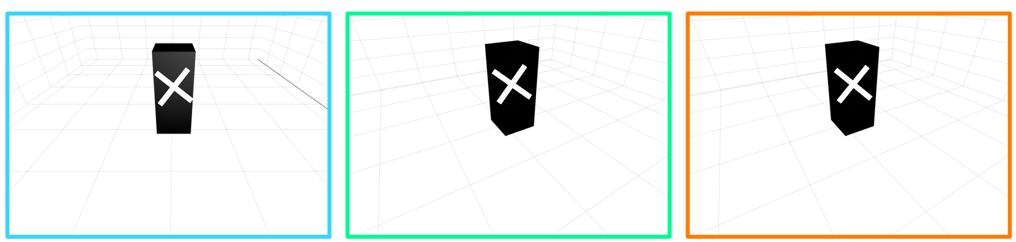
$x_{d,i}(k)$ desired trajectory point

$b_{1_{d,i}}(k)$ desired first body direction



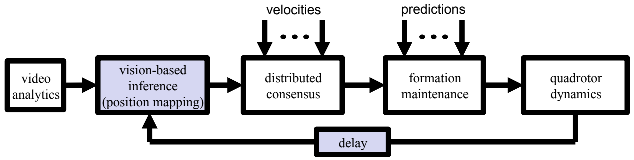
$\tilde{x}_{t,i}(k) \in \mathbb{R}^2$ $\rightarrow$

detected target



- T. Lee *et al.*, "Geometric tracking control of a quadrotor UAV on SO(3)," in ICRA 2010

Vision-based inference



We want to maintain the target centred on each camera plane

Each flying camera adapts its velocity

Gain

regulariser

$$m_i(k) = 1 - \exp\left(-\frac{1}{2}\tilde{x}_{t,i}(k)^T \Sigma_m^{-1} \tilde{x}_{t,i}(k)\right)$$

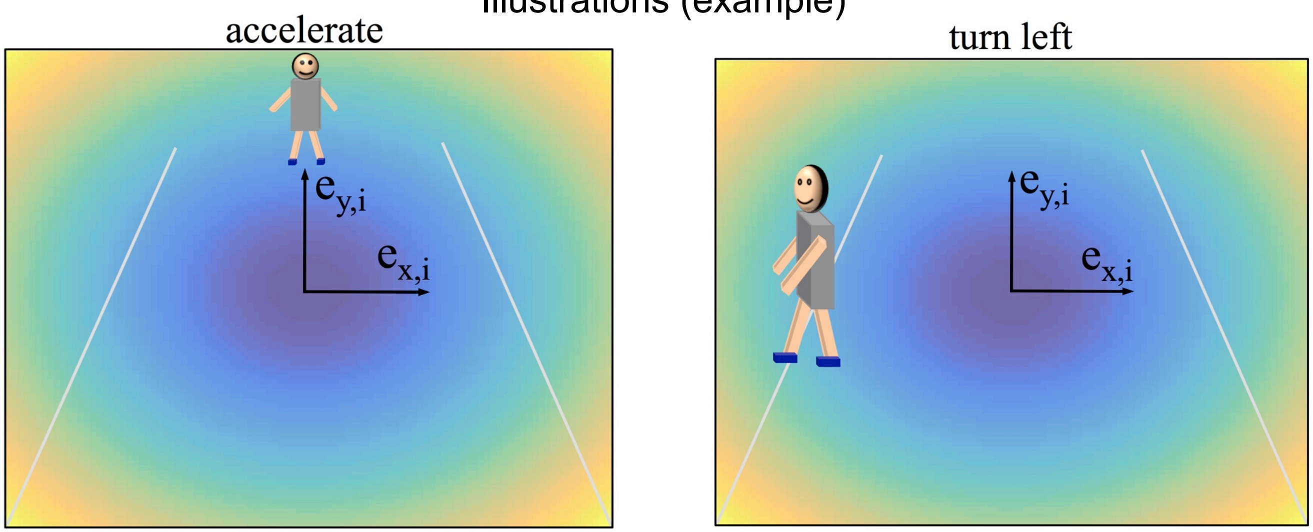
Direction (e.g. x-axis)

amplifier term $\quad a_{x,i}(k) = sgn(\tilde{x}_{t,i}(k) \cdot e_{x,i}) m_i(k)$

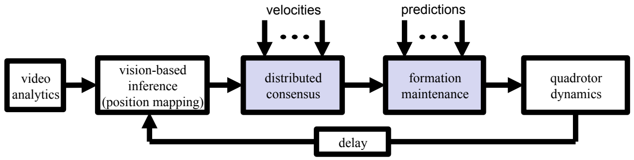
$$v'_{x,i}(k) = \alpha a_{x,i}(k) + v_{x,i}(k - \Delta_k) \quad \text{if } \dot{a}_{x,i}(k) > 0$$

$$v'_{x,i}(k) = v_{x,i}(k - \Delta_k) \quad \text{otherwise}$$

Illustrations (example)



Distributed formation control



Velocity visually inferred could be noisy $\rightarrow$ velocity agreement

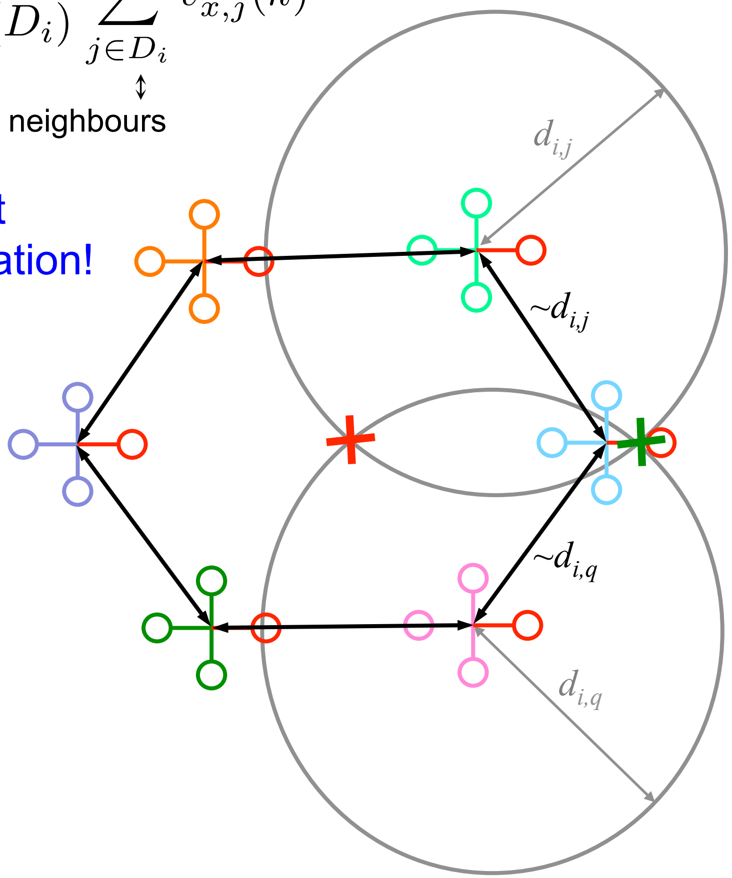
$$v_i(k) = (v_{x,i}(k), v_{z,i}(k), v_{z,i}(k))^T$$

$$v_{z,i}(k) = v_{z,i}(0)$$

$$v_{x,i}(k) = \frac{1}{card(D_i)} \sum_{j \in D_i} v'_{x,j}(k)$$

$\updownarrow$
neighbours

No sufficient
to maintain formation!



Formation maintenance

[Anderson2008]

$$x^c_{d,i}(k) = x_i(k - \Delta_k) + v_i(k)\Delta_k$$

$$\boxed{p^c_i(k)} = \arg\min_x \{||x - x^c_{d,i}(k)||\}$$

$\updownarrow$
circle intersection points

$$x_{d,i}(k) = \begin{cases} x^c_{d,i}(k) & \text{if } |\epsilon_{i,j}| < \varepsilon \text{ or } |\epsilon_{i,q}| < \varepsilon \\ p^c_i(k) & \text{otherwise,} \end{cases}$$

$\updownarrow$

$$\epsilon_{i,j} = ||x^c_{d,i}(k) - x^c_{d,j}(k)|| - d_{i,j}(0)$$
$$\epsilon_{i,q} = ||x^c_{d,i}(k) - x^c_{d,q}(k)|| - d_{i,q}(0)$$

B.D.O. Anderson *et al.*, “UAV formation control: Theory and application,” in Recent Advances in Learning and Control, 2008

Simulation results

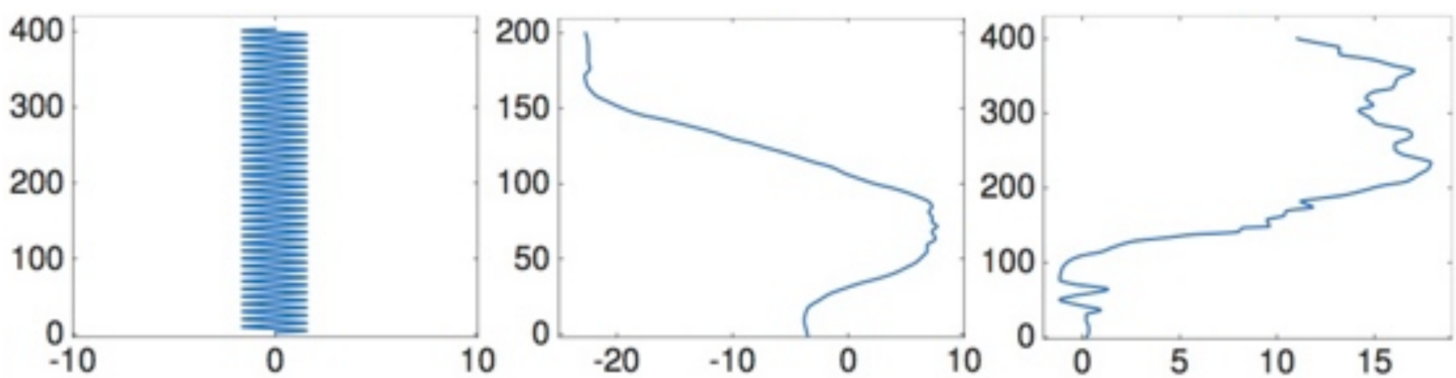
- Evaluate → ratio of cameras viewing a moving target

$$\frac{\text{number of cameras viewing the target}}{\text{total number of cameras in the formation}}$$

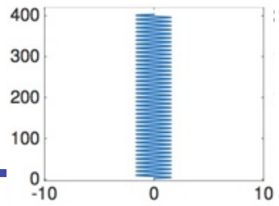
- Flying cameras initialised on target

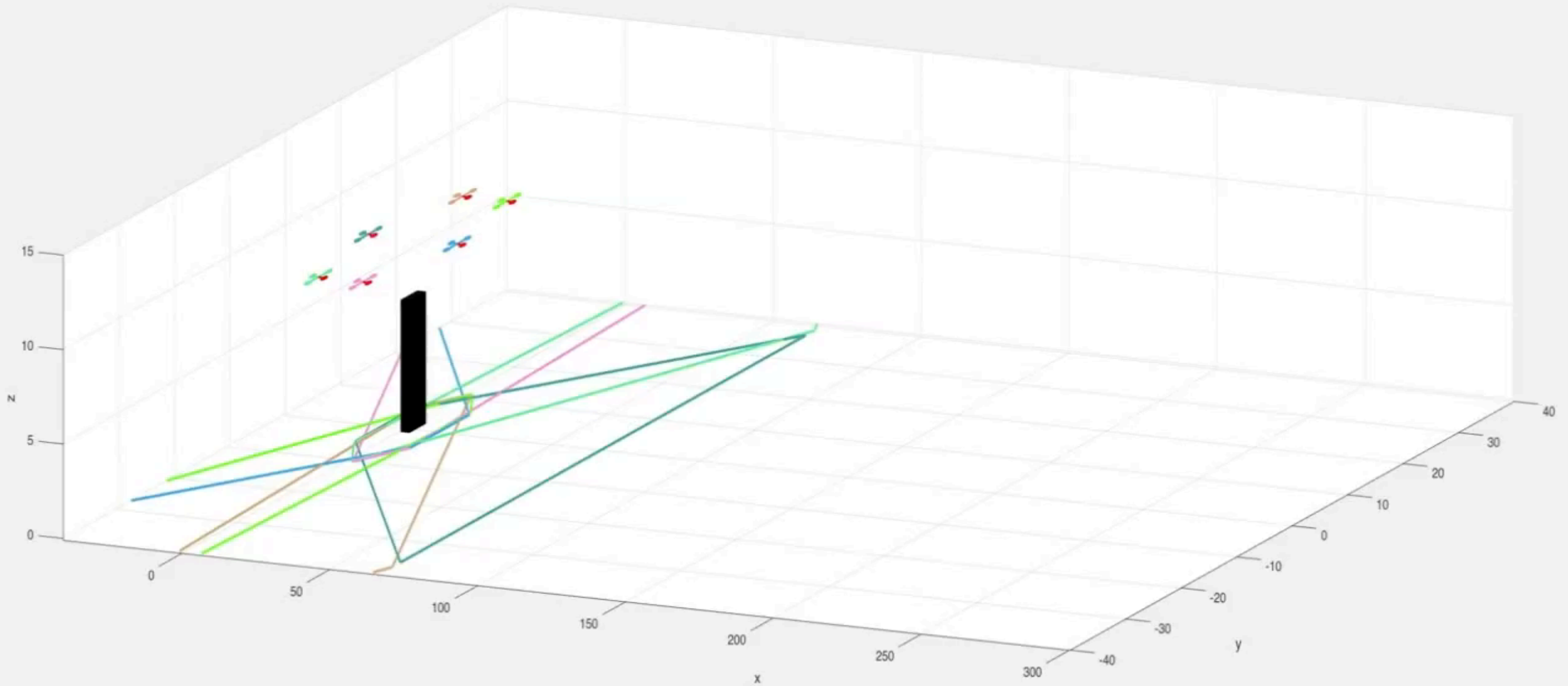
$$x_i(0) = \Big(\underset{15}{L}\, cos((i-1)\frac{\pi}{N/2}),\ L\, sin((i-1)\frac{\pi}{N/2}),\ \underset{10}{A}\Big)^T \qquad v_i(0) = (2\Delta_k, 0, 0)^T\ \forall i \quad \Delta_k = 0.04$$

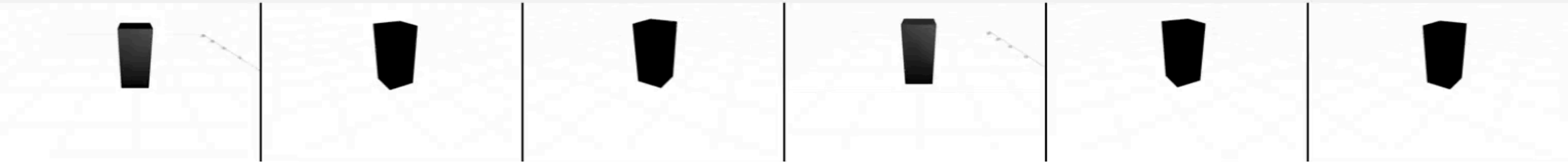
target trajectories



Flying camera formation







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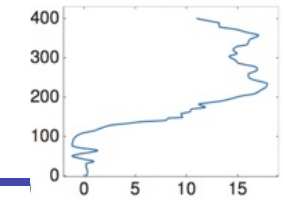
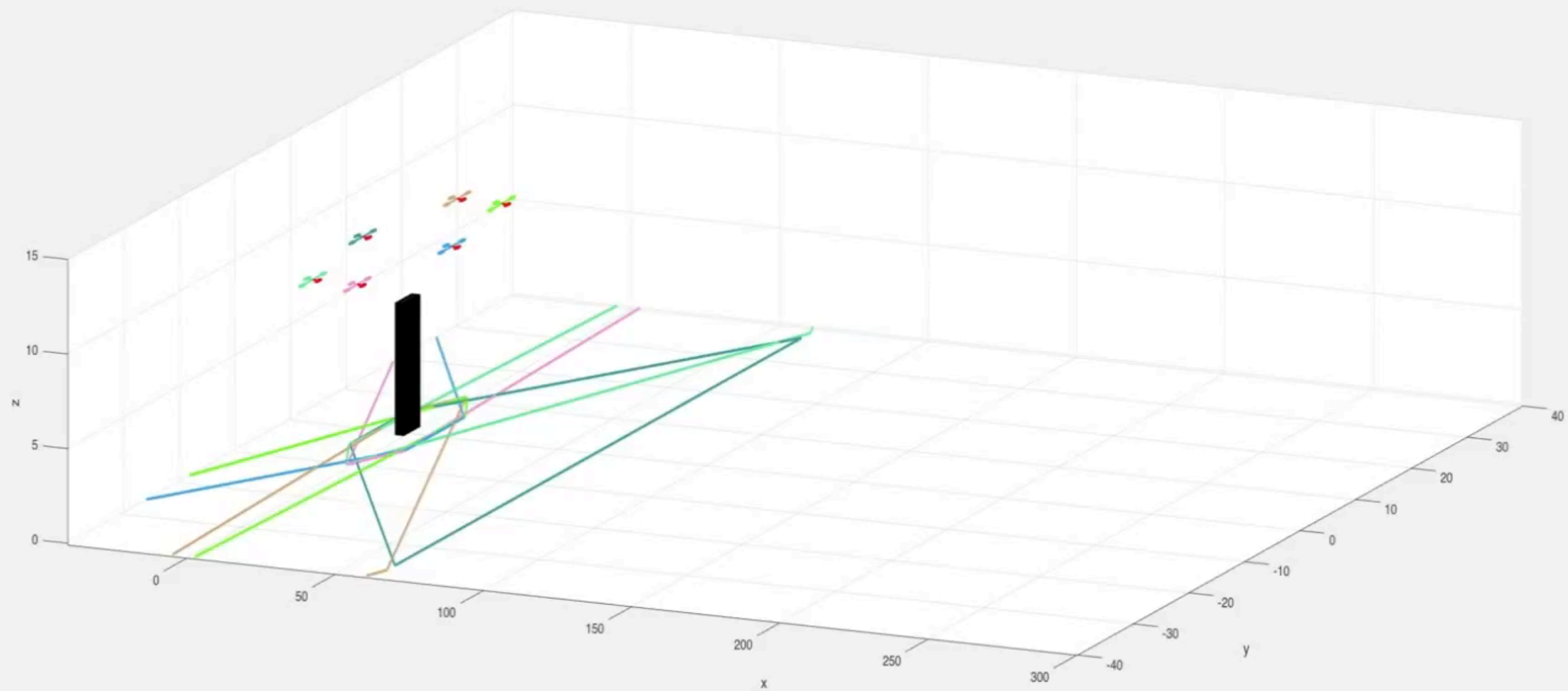
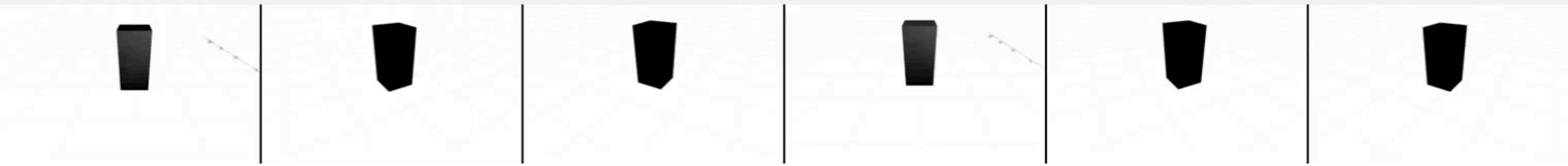
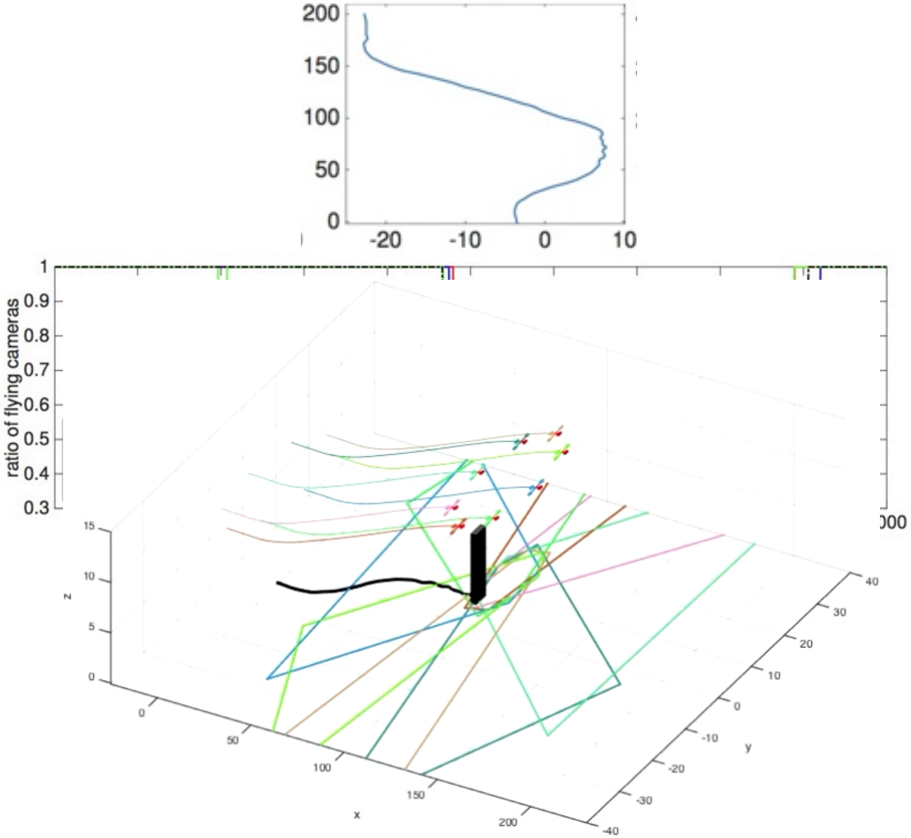
Flying camera formation

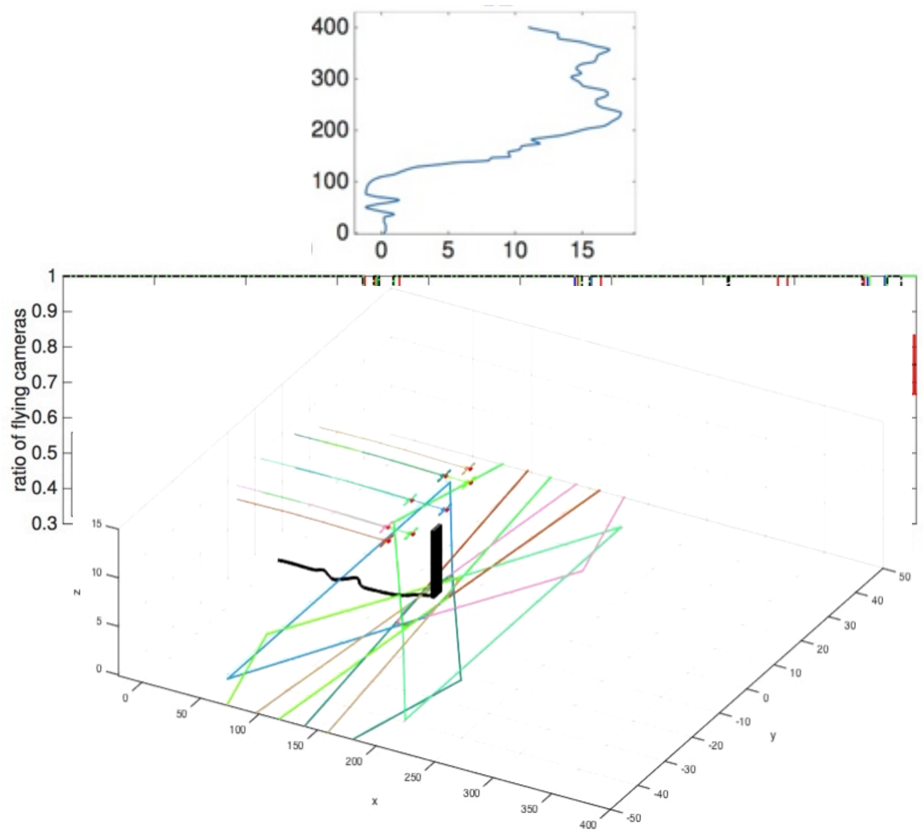






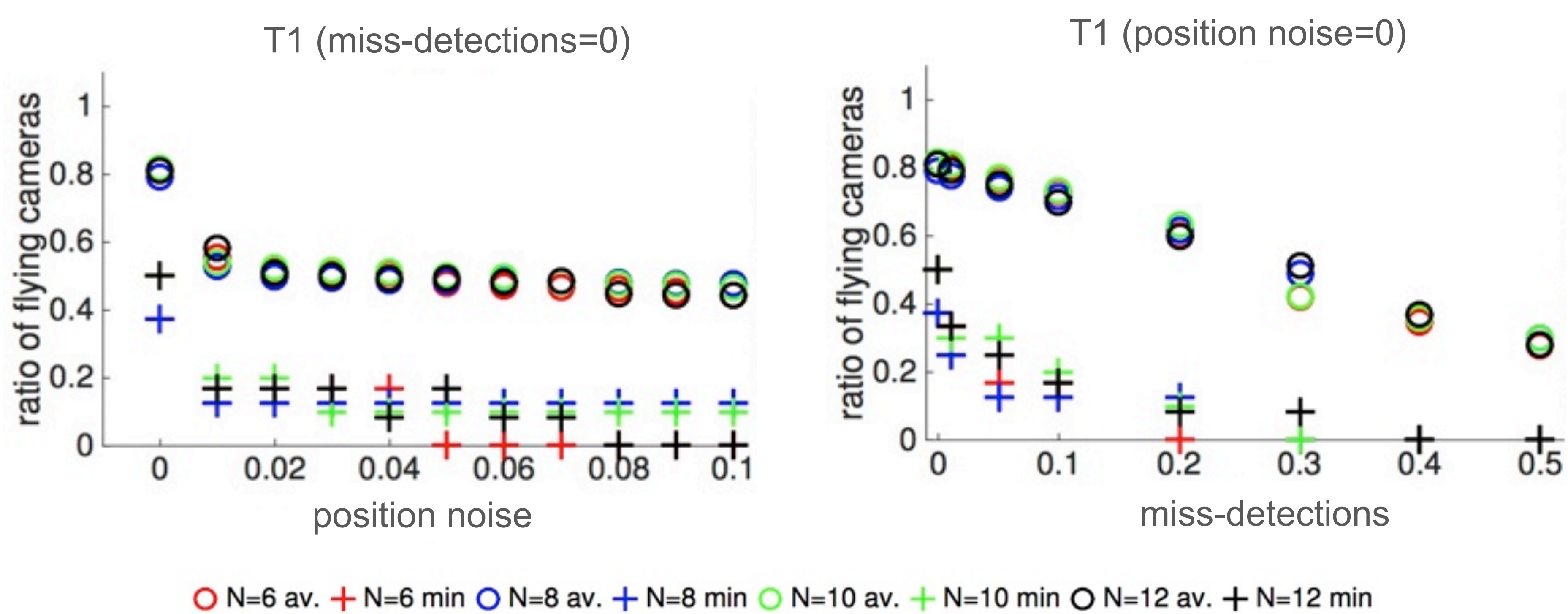
Robustness to target motion variations





Noisy target detections

- Model → *inaccurate target position* and *miss-detections*



Conclusions

- Distributed algorithm helps maintaining formation in presence of noisy detections
- Formation of flying cameras enables target following via visual feedback (no GPS location)
- Few cameras viewing the target allow the whole formation to avoid target loss
- Future work
  - Multi-altitude formation
  - PID controller to improve stability

Reference papers

- F. Poiesi and A. Cavallaro, "**Distributed vision-based flying cameras to film a moving target**," IEEE Proc. of IROS, Hamburg, GE, Sep 2015

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