Formation Control and Cooperative Localization for a Team of Quadrotor UAVs

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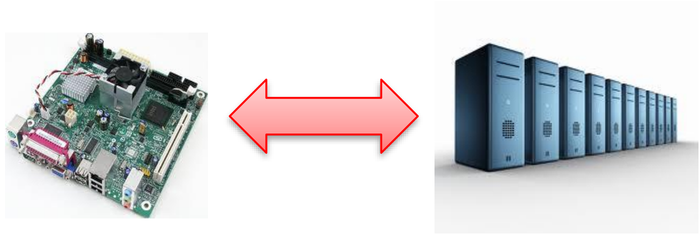
One vs. many

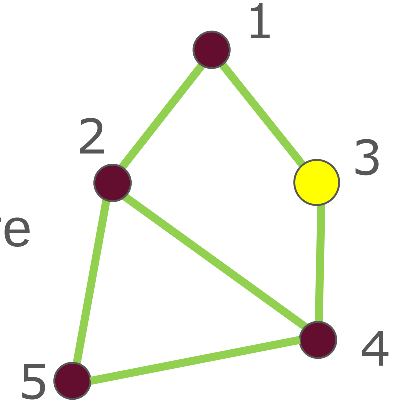
- versatility
- efficiency
- low cost
- robustness and fault tolerance

Decentralization

- local control/estimation complexity is related to:
  - the amount of needed information (sensed, communicated)
  - the needed computing power and memory requirements



- limited sensing/communication/computing/memory resources → need of decentralized (scalable) control/estimation algorithms
  - avoid measurement of the state of the whole group
  - keep a constant complexity per neighbor

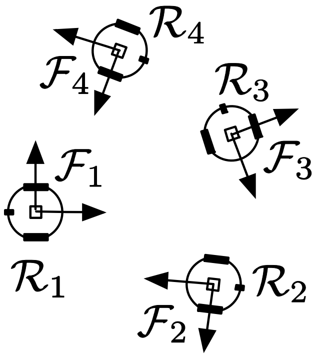


- however: decentralized (scalable) algorithms often require propagation of information within the group
  - need to preserve group connectivity

Local sensing

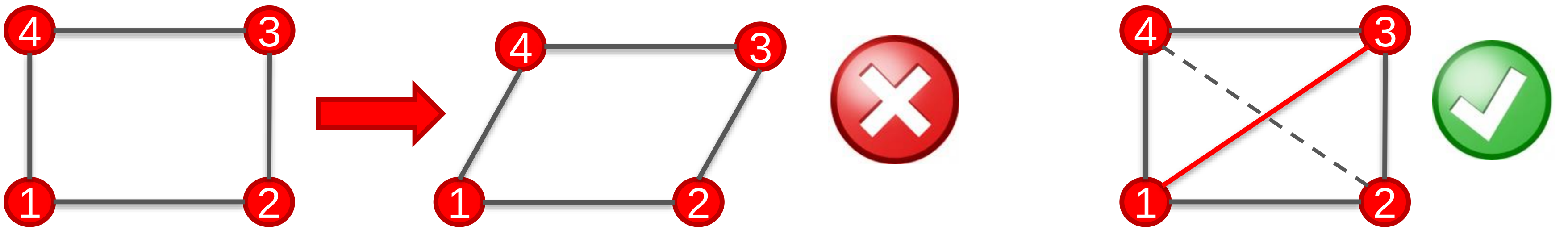
- lack of centralized facilities → only local and relative sensing
  - sensor limitations (e.g., field of view, range, occlusions, noise, delays, quantization)
  - partial measurements of the agent states (e.g., distance vs. relative position)
  - measurements expressed in the agent body frame → no absolute global frame (e.g., need to agree on a common orientation)



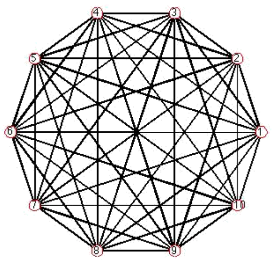



- need to preserve formation rigidity (~ allow for cooperative localization in a common reference frame from onboard relative and partial sensing)

Rigidity



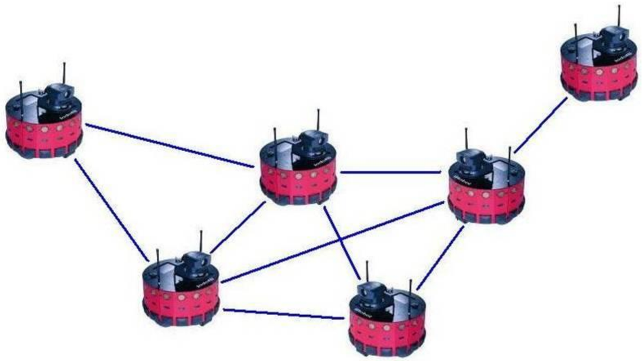
- a “framework” (graph + agent poses) is rigid if it cannot be deformed “while preserving the pair-wise geometrical constraints”



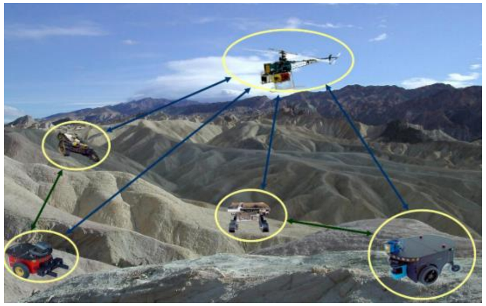
- complete graph: rigid but need to measure/control/enforce $N(N-1)/2$ constraints (the complexity is $O(N^2)$)
- however, rigidity is often possible with only a $O(N)$ set of constraints
- e.g.: distance constraints on the plane

	$N(N-1)/2$	$2N-3$
$N=3$	3	3
$N=4$	6	5
$N=10$	45	17

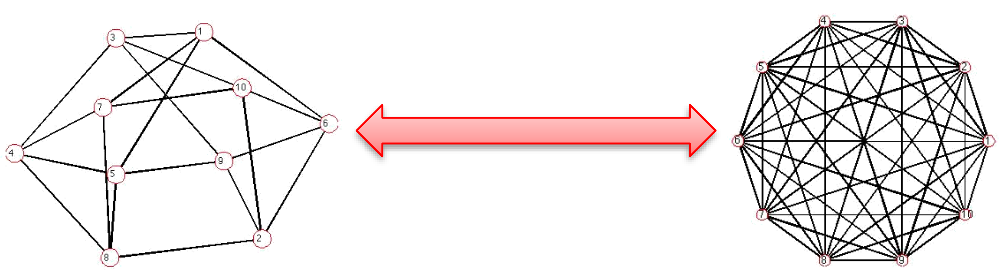
Rigidity: what for ?



- formation control
  - regulation of inter-robot constraints = the desired robot positions (shape) can be reached
- relative localization (in a common shared frame)
  - measurement of inter-robot constraints = the current robot positions (shape) can be reconstructed



- and, again, no need of a complete graph
  - linear complexity $O(N)$ vs. quadratic complexity $O(N^2)$

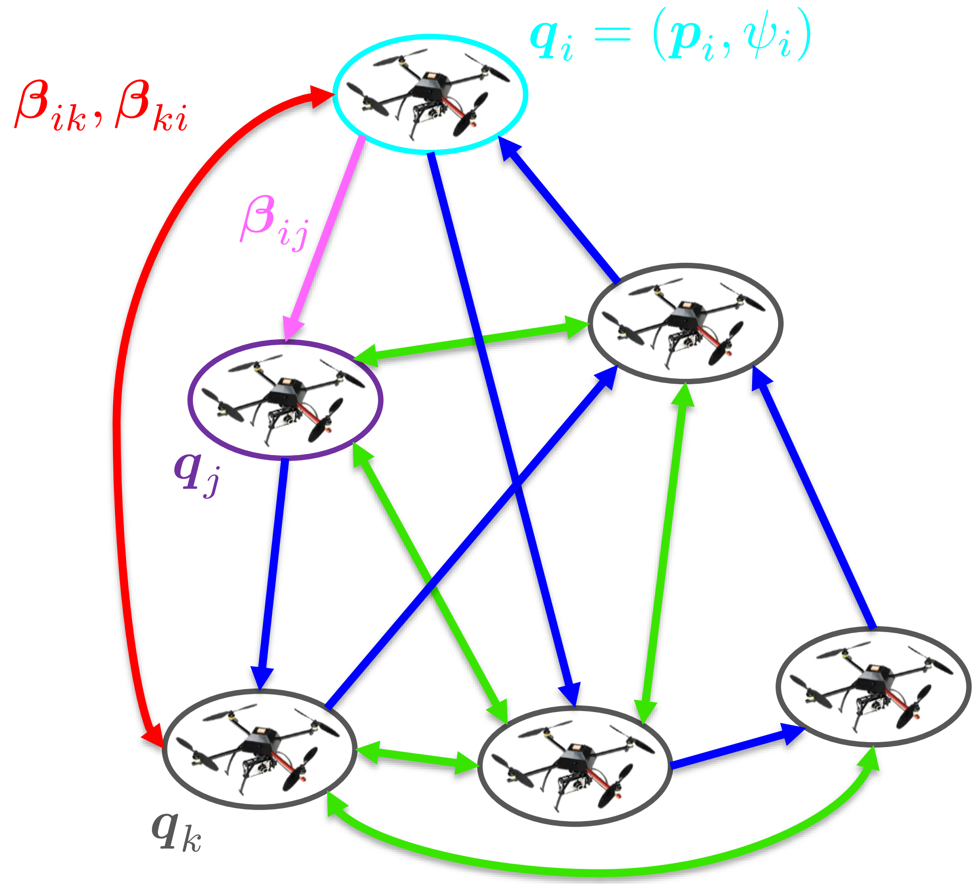


Bearing based formation control of UAVs

- team of N UAVs

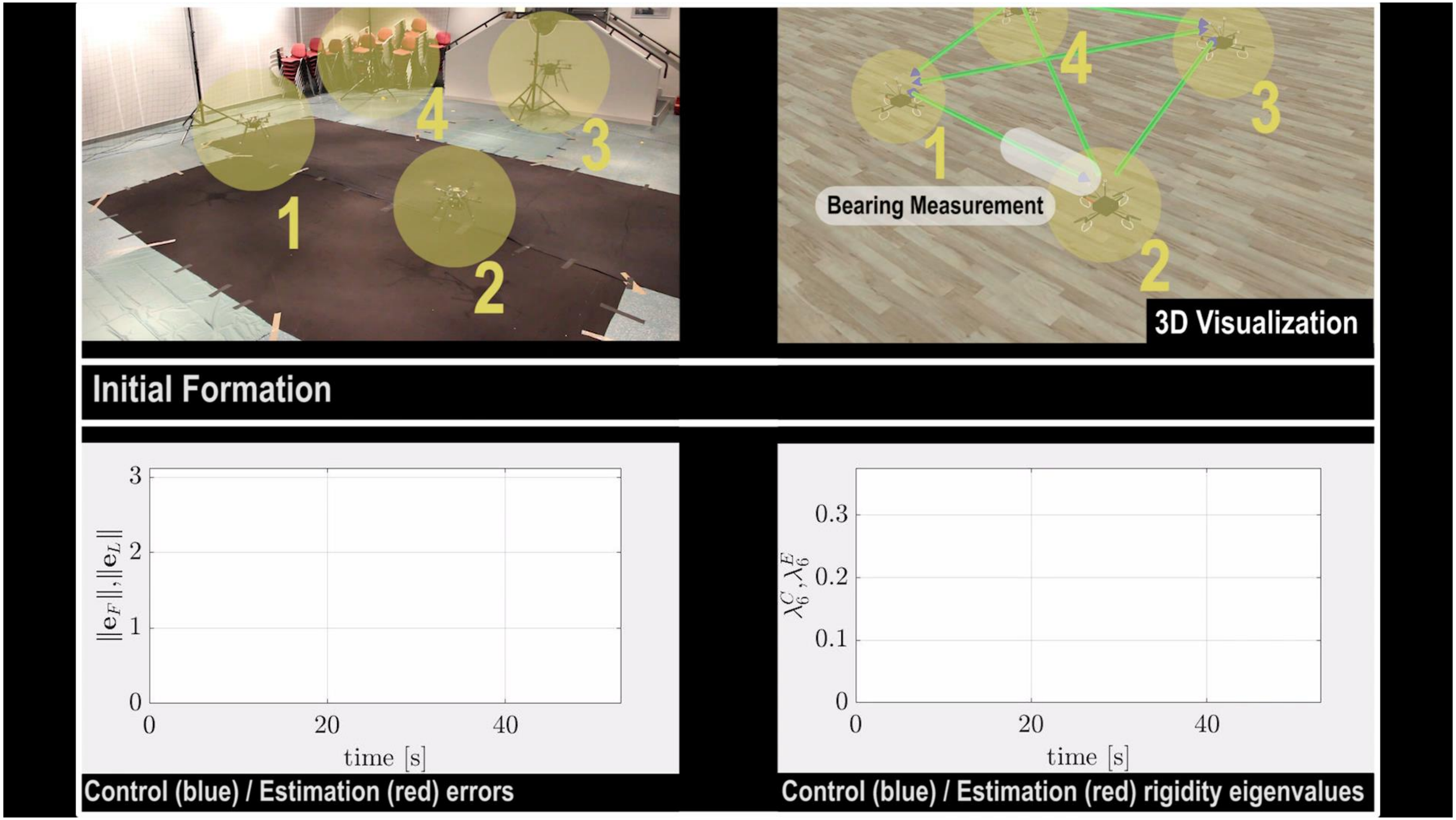
$$\begin{bmatrix} \dot{\boldsymbol{p}}_i \\ \dot{\psi}_i \end{bmatrix} = \begin{bmatrix} \boldsymbol{R}_i(\psi_i) & 0 \\ \boldsymbol{0}_3 & 1 \end{bmatrix} \begin{bmatrix} \boldsymbol{u}_i \\ w_i \end{bmatrix}$$

$$\boldsymbol{\beta}_{ij} = \boldsymbol{R}_i(\psi_i)^T \frac{\boldsymbol{p}_j - \boldsymbol{p}_i}{\|\boldsymbol{p}_j - \boldsymbol{p}_i\|}$$



- goal:
  - control formation shape
  - estimate formation shape

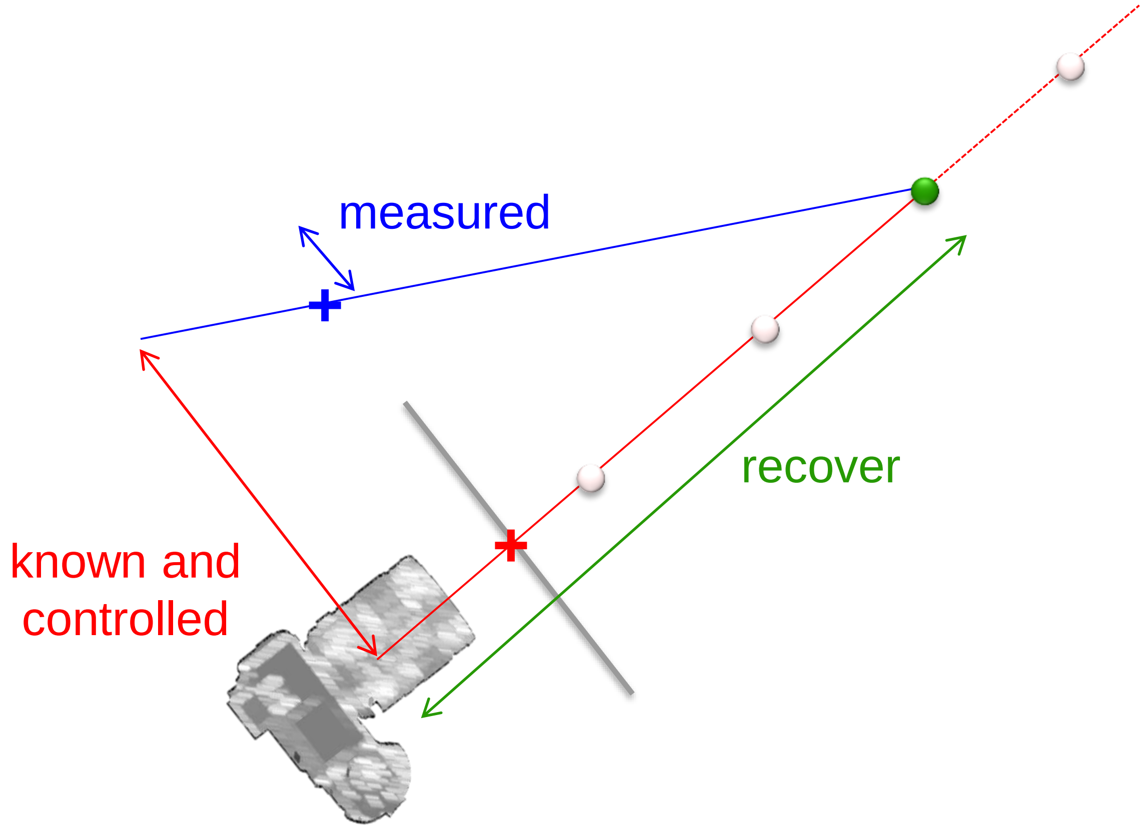
Bearing based formation control



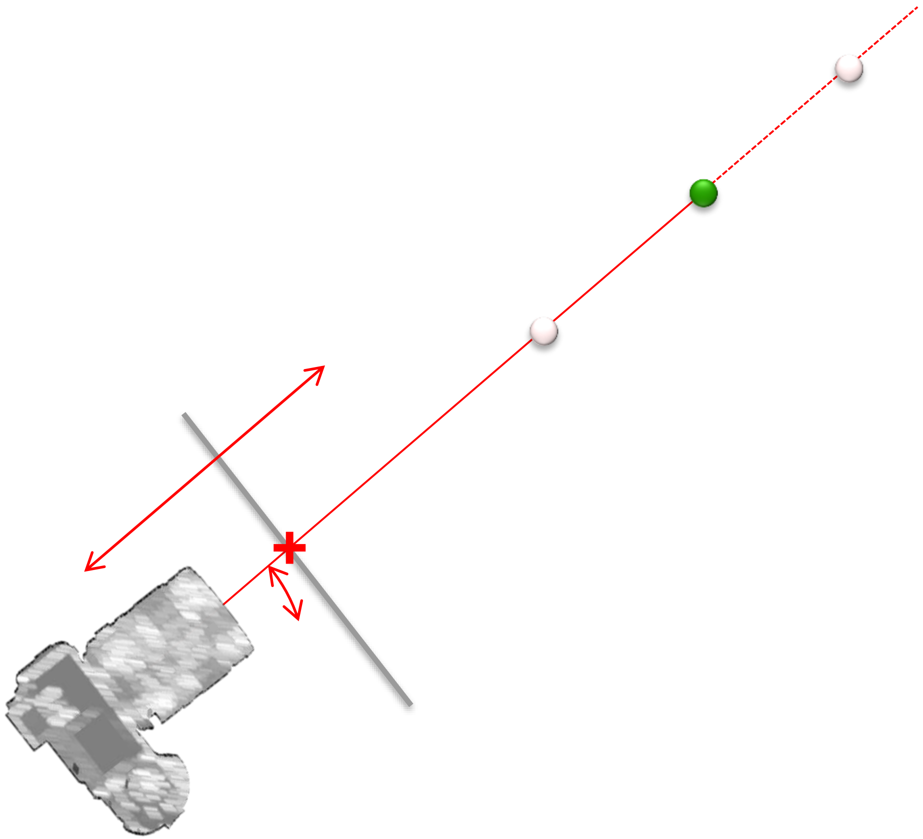
F. Schiano, A. Franchi, D. Zelazo and P. Robuffo Giordano, “A Rigidity-Based Decentralized Bearing Fromation Controller for Groups of Quadrotor UAVs,” in IEEE/RSJ IROS 2016, Daejeon, Korea, Oct. 2016.

Distance estimation from motion

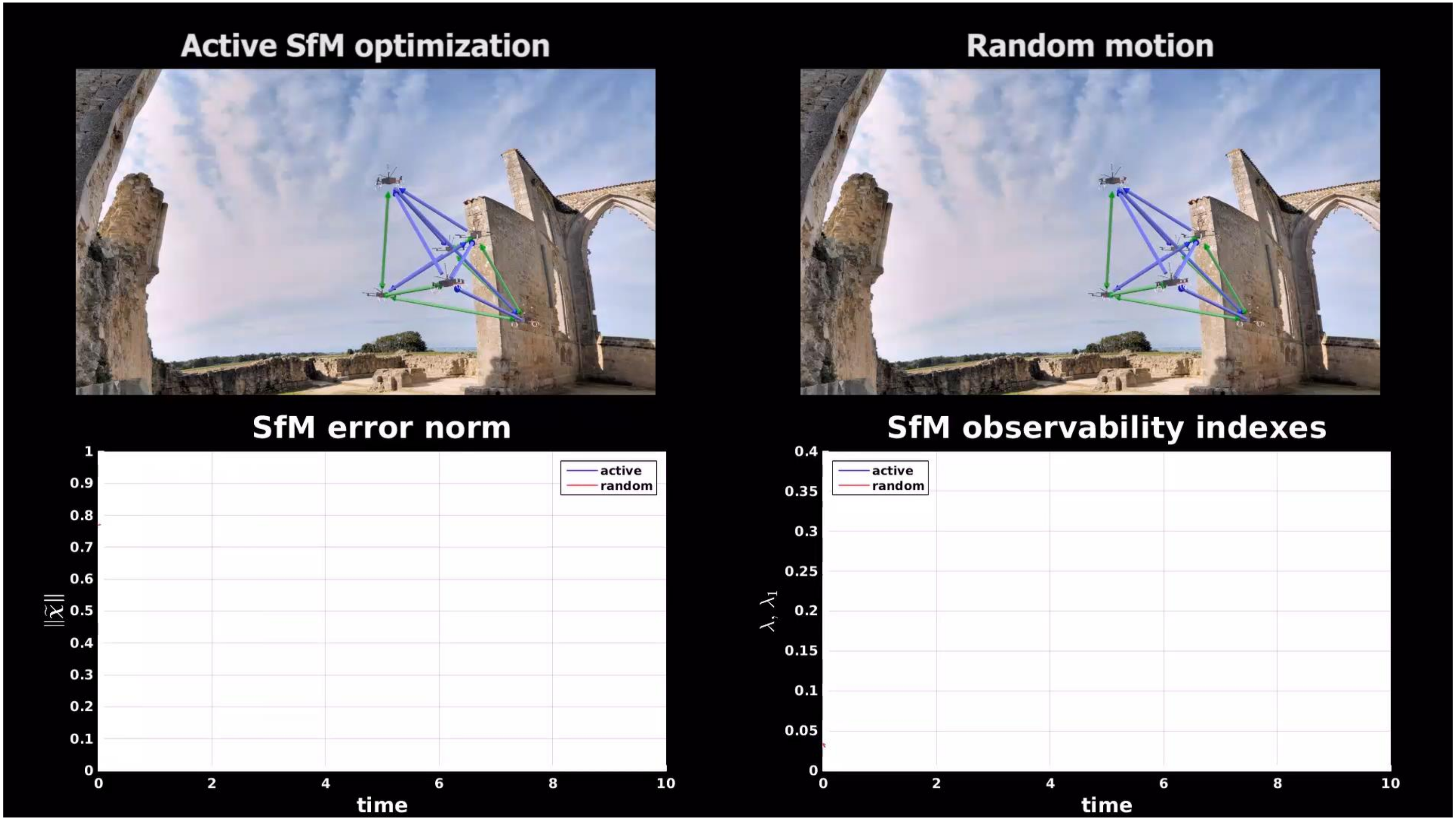
- formation scale cannot be recovered from bearings only
- however the scale is necessary in some applications and for localization algorithms to converge with moving agents



All motions are not made equal



Active decentralized scale estimation



R. Spica, and P. Robuffo Giordano, “Active Decentralized Scale Estimation for Bearing-Based Localization,” in IEEE/RSJ IROS 2016, Daejeon, Korea, Oct. 2016.

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Thanks for your attention