Estimation of Continuous Environments by Robot Swarms: Correlated Networks and Decision-Making

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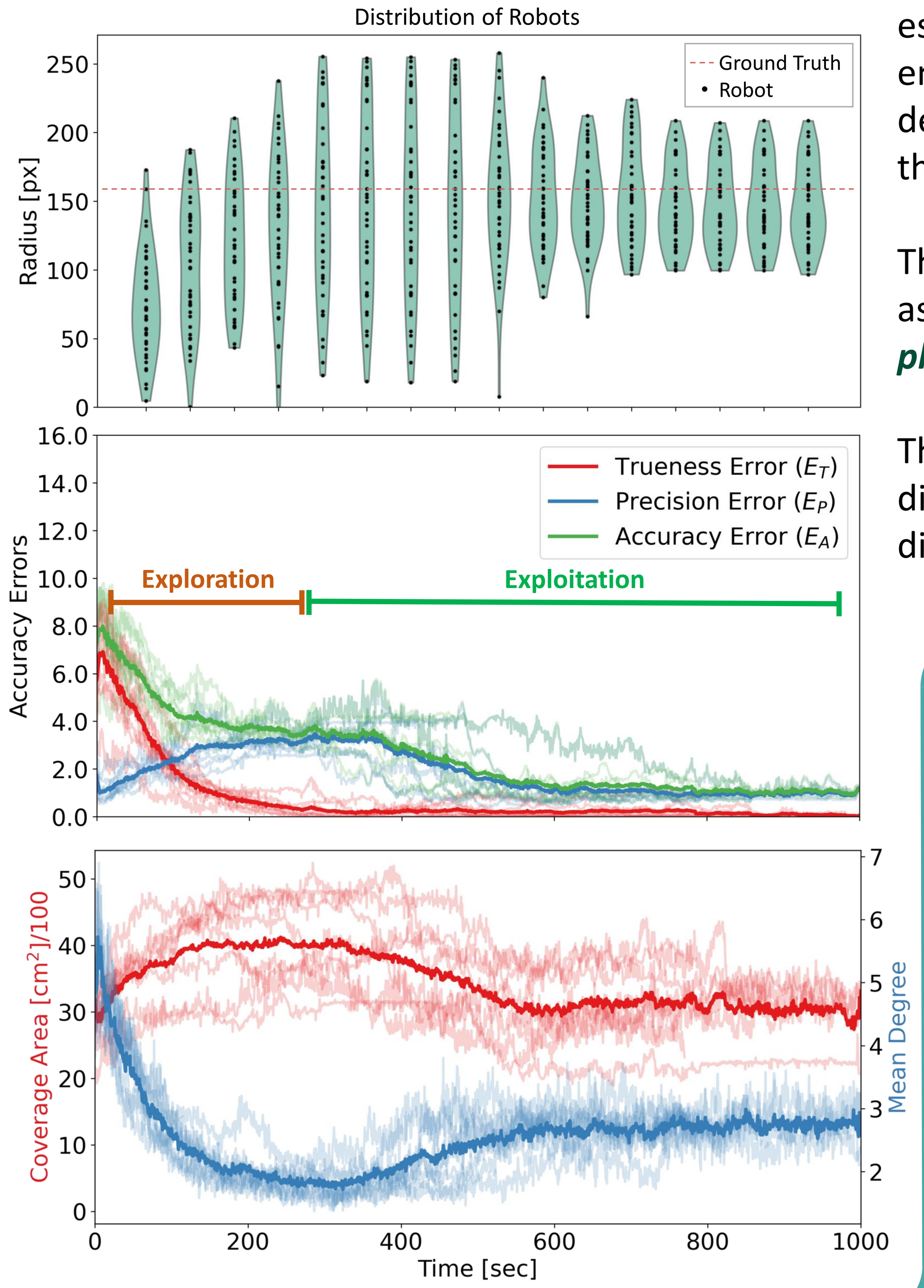
Speed-vs-Accuracy Tradeoff (SAT) in Contour Capturing



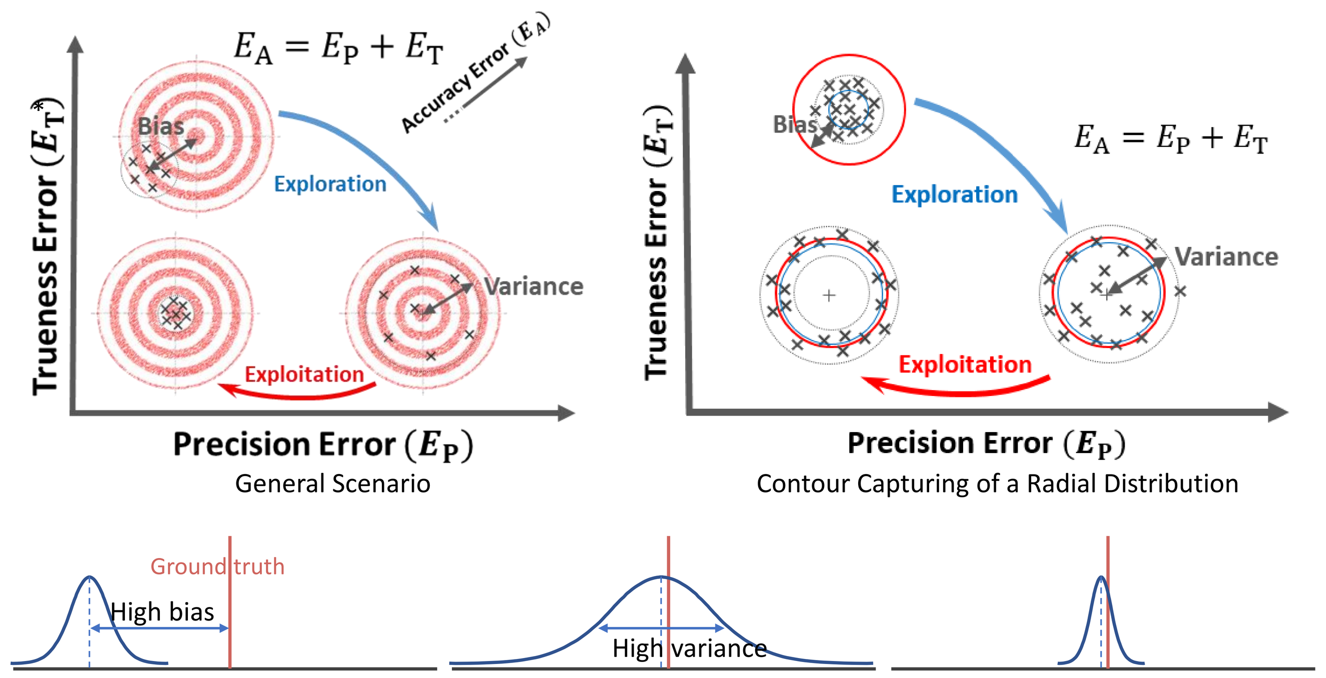
We propose a method for a group of Kilobots to estimate the mean light intensity distributed in an environment. The swarm starts from a biased, dense initial distribution and gets disperse during the ***dispersion*** (exploration) phase.

The exploration phase starts with a ***local averaging*** as a consensus method, which is followed by a ***phototaxis*** behavior.

The emerging collective behavior is a self-organized, distributed contour capturing of the light distribution in the environment.

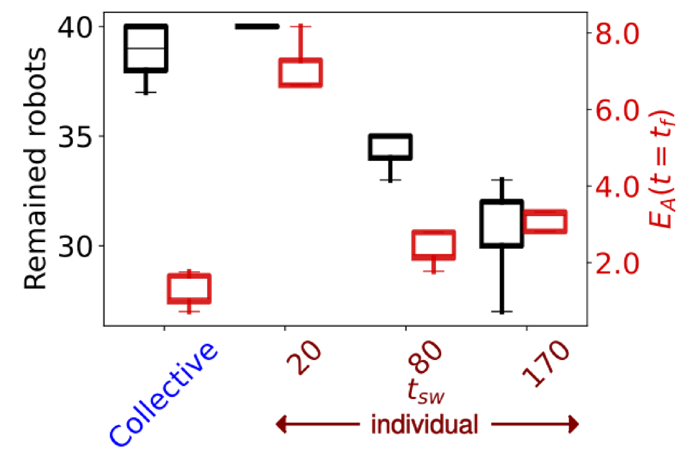
Accuracy and Exploration-Exploitation

By decomposing the total Accuracy Error into Trueness Error (Bias) and Precision Error (Variance) we show how exploration and exploitation improve the collective estimation accuracy.



Comparison

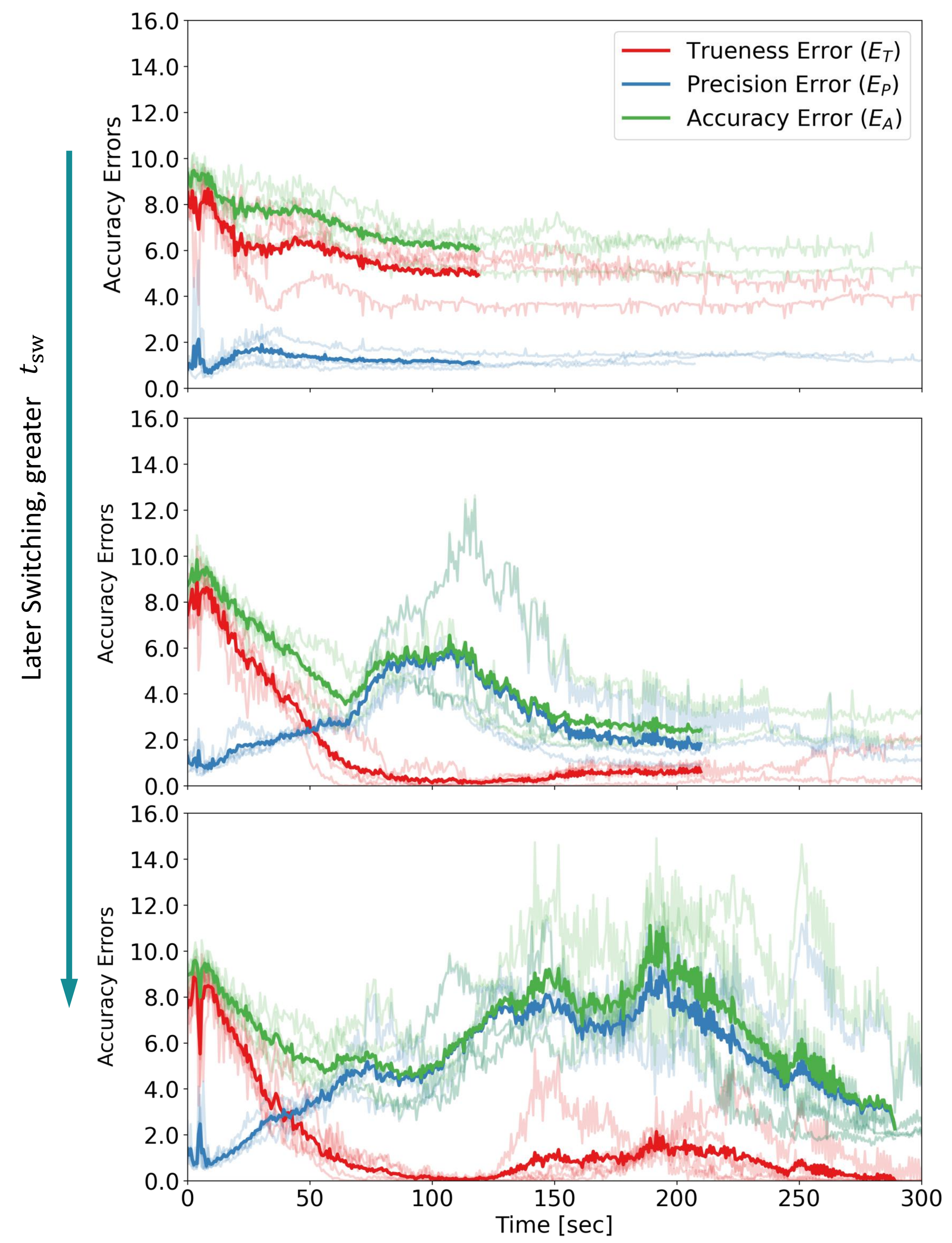
For the comparison between the proposed and baseline approaches we considered the number of robots remained in the accuracy error and area of interest as performance metrics.

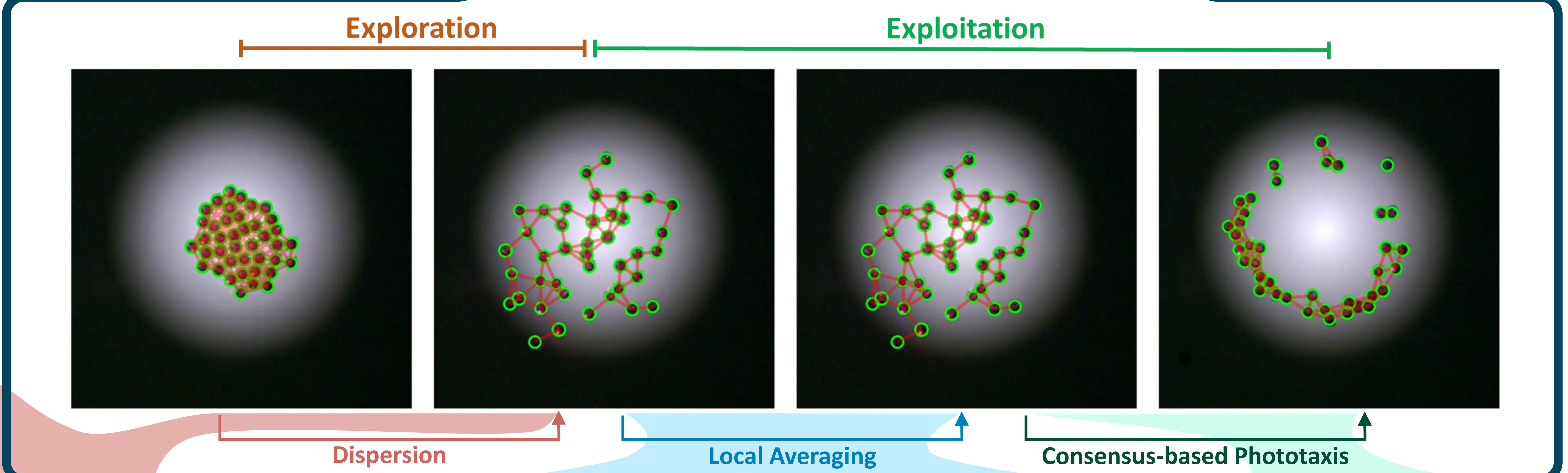


Control Study:
Individualistic Approach

As an alternative, robots can explore the environment individually, and switch to exploitation at a certain time (t_{sw}), that is the control parameter.

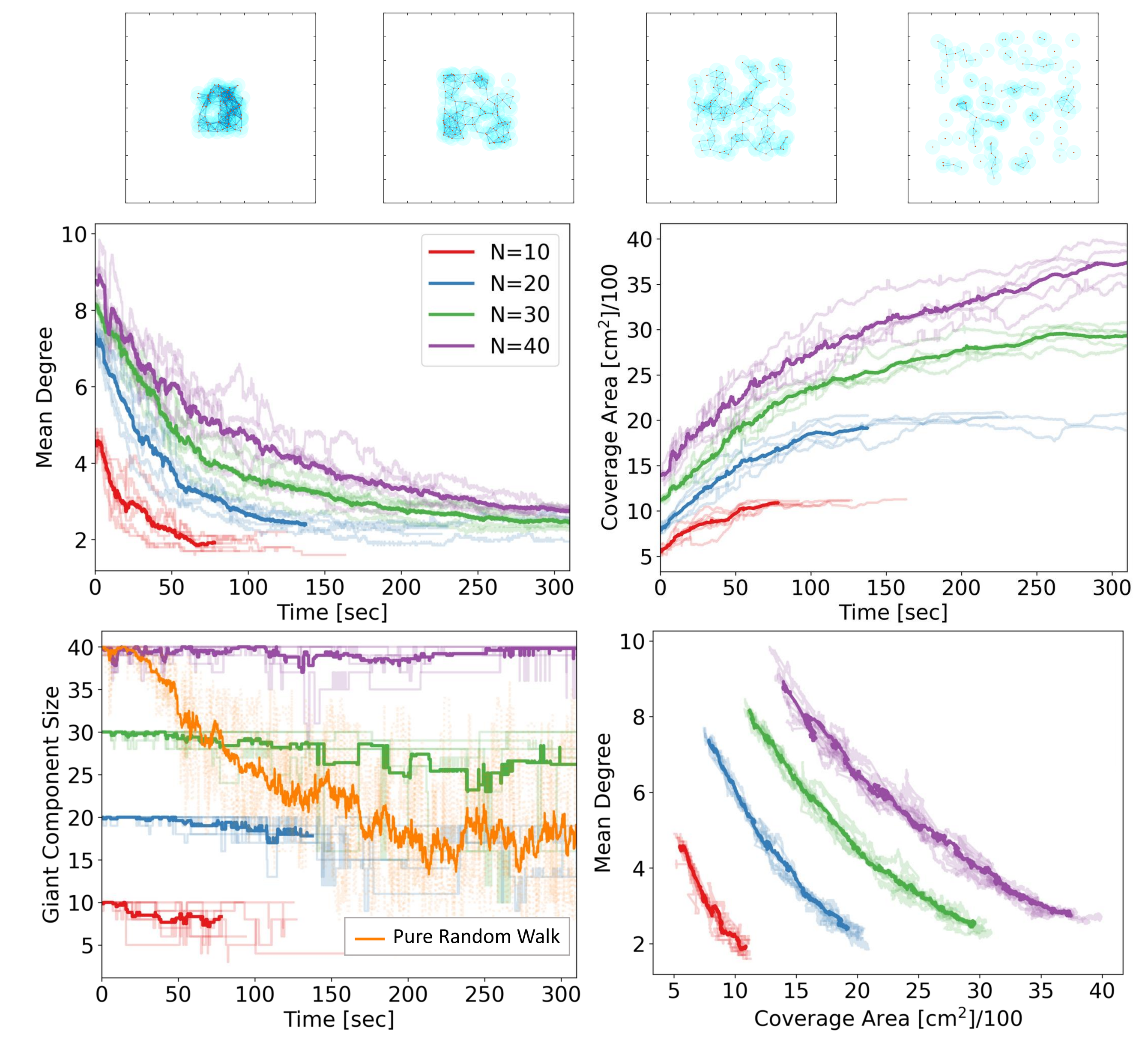
We evaluated the accuracy of the swarm for three different switching times.





Network Connectivity vs. Coverage Area Trade-off

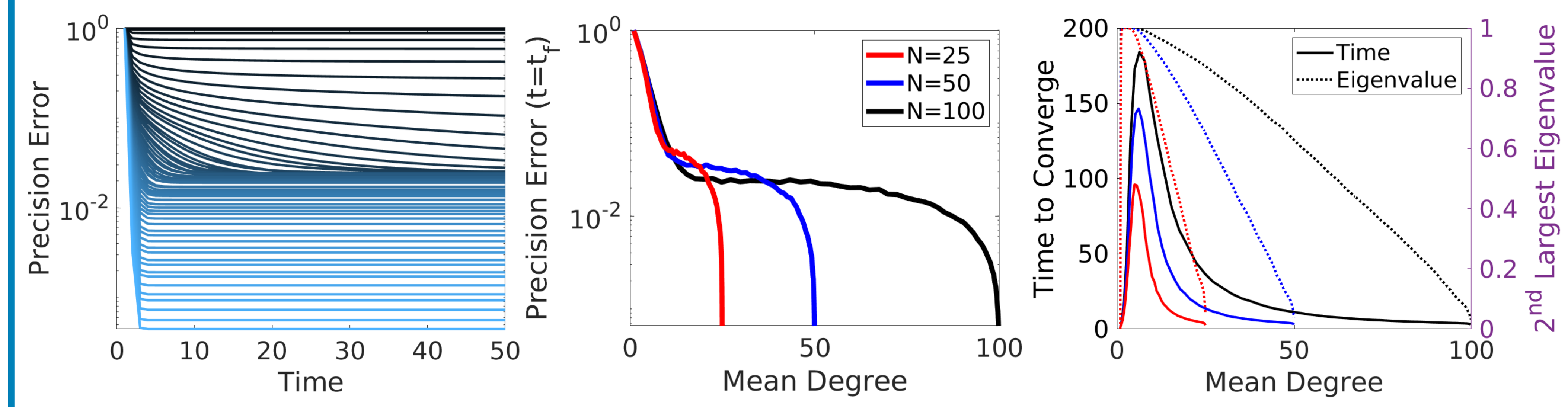
During the dispersion, the network connectivity and coverage area develop in opposing directions making a tradeoff, which the swarm is supposed to balance in a distributed manner.

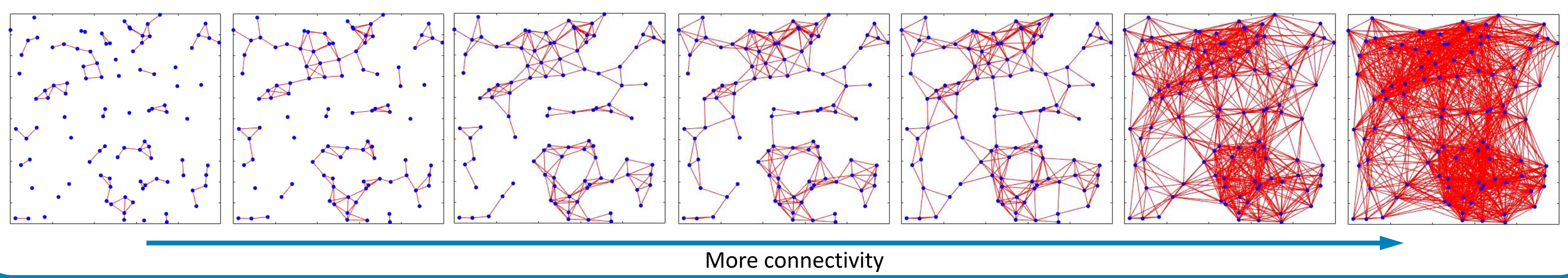


Network Connectivity and SAT in Information Diffusion:

The network connectivity also changes the speed and accuracy of the information diffusion on the network. We created geometrical random networks with varying communication range and measured the precision error over time. We considered the DeGroot model for the consensus method, as below:

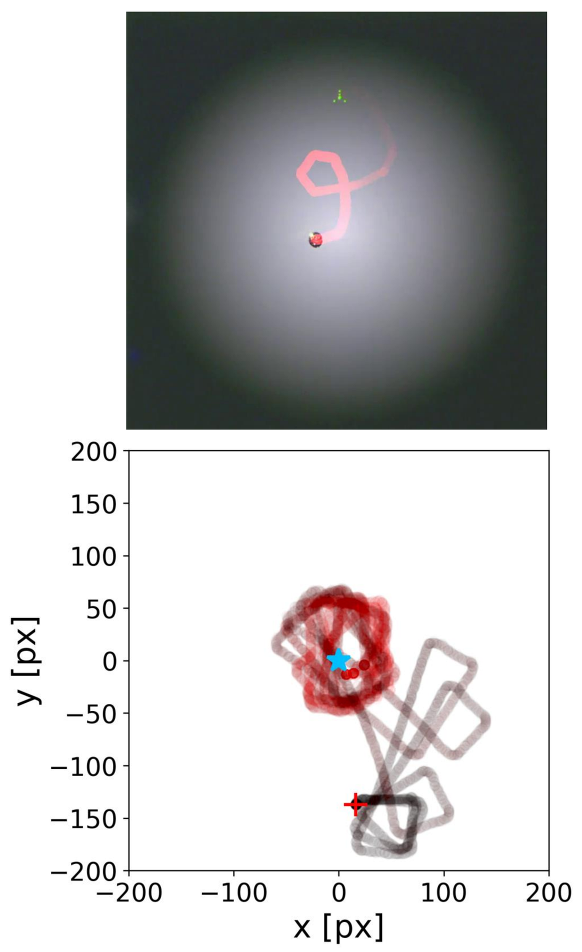
DeGroot's Naïve learning in social systems: $z_i^{(t+1)} = \alpha_i \times z_i^{(t)} + (1 - \alpha_i) \times \bar{z}_{soc,i}^{(t)}$ $\quad \bar{z}_{soc,i}^{(t)} = \frac{1}{N_i} \sum_{j \in N_i} z_j^{(t)}$



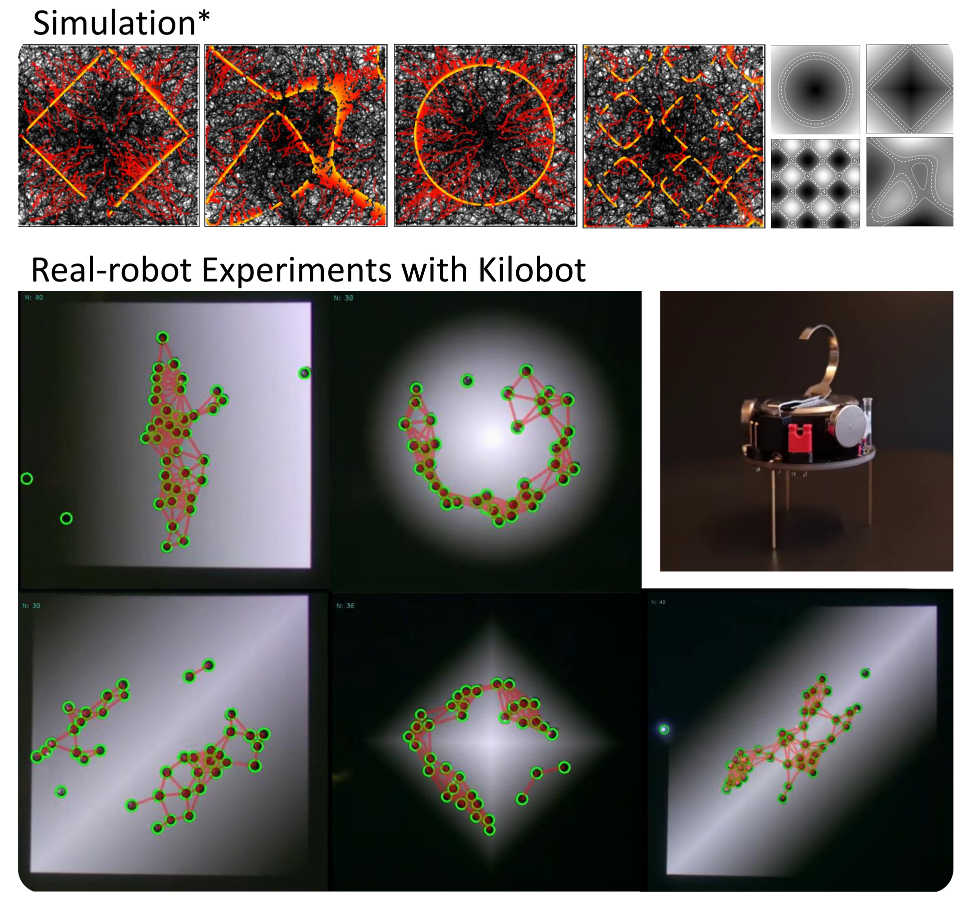


Consensus-based Phototaxis

We implemented phototaxis as a sample-wise optimization algorithm, but used the consensus value as the setpoint.



From Simulation to Reality



More Information and Contact

* Our MRS Paper | Supplementary video | Contact

[*]: [Raoufi, et al. 2021 "Speed-vs-accuracy tradeoff in collective estimation: an adaptive exploration-exploitation case". IEEE MRS]