A Rendezvous Algorithm for Multi-agent Systems in Disconnected Network Topologies

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Outline

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2. Problem Statement
3. Proposed Solution
4. Simulation Results
5. Concluding Remarks

Motivation

- Multi-Agent Systems (MAS) - a network composed of mobile agents with the objective of converging to a single location.
- No centralized infrastructure - implies the need for a decentralized algorithm to compute the actuation.
- Applicable to exploration missions - a group of robots with the target of sensing as much ground as possible.

Traditional Solution

- Typical solutions use consensus algorithms [1] [2], can cope with asymmetric wireless links.
- Consensus algorithms can be made to work with noisy measurements [3].

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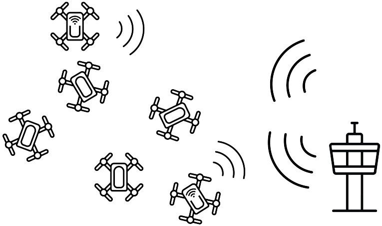
- Consensus algorithms can be made to work with noisy measurements [3].
- Problems:
  1. Difficult to incorporate mission plane constraints;
  2. Multiple clusters if the initial topology was not connected;
  3. Possible collisions.

Scenario

- Communication towers provide localization with errors;
- Transmission resorts to directional antennae;
- Agents listen to the channel to discover neighbors.



Main issues

- Possible collisions;
- Position and velocity received with errors;
- Non-connected and unknown topologies;
- Limited unidirectional communication.

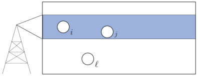


Figure: For simplicity, communication is assumed to occur in a perfect strip.

Proposed Algorithm

- Exploration Phase:
  - Sense the medium to get polytopic state estimates for the neighbors — $X_j(k)$
  - Find centers $c_j(k)$ for the balls enclosing the polytopes
  - Compute a dispersion vector

$$v_i(k) = c_i(k) - \frac{1}{|\mathcal{N}_i(k)|} \sum_{j \in \mathcal{N}_i(k)} c_j(k)$$

  - Move according to

$$x_i(k+1) = x_i(k) + \min\left(a_i(k), \varphi_i\right) \frac{v_i(k)}{\|v_i(k)\|} \tag{1}$$

- Collisions can be avoided if $a_i(k)$ is selected appropriately and does not exceed the maximum allowed movement φ_i.

Proposed Algorithm

- Convergence Phase:
  - Store previous set-valued positions — $X_j(k-1)$
  - If movement is below a given threshold, select a converging direction

$$v_i(k) = -v_i(k)$$

  - Move according to

$$x_i(k+1) = x_i(k) + \min\left(a_i(k), \varphi_i\right) \frac{v_i(k)}{\|v_i(k)\|} \qquad (2)$$

Collision Avoidance

- Use of Set-Valued Observers (SVOs) [4] to estimate positions;
- The magnitude of the actuation is saturated to prevent collisions;
- Collision-free guarantees since SVOs are guaranteed to contain the true state.
- Overbounding by a ball makes an efficient testing.

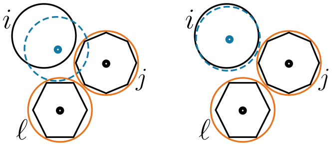


Figure: SVO-based collision avoidance.

Results

- Given a mission plane of size m and a strip of size $2h$
- No noise
- If there is a sufficient number of nodes:

$$n \geq \lceil \frac{m}{h} \rceil + 1 \tag{3}$$

- The algorithm converges to a single cluster
- If there is noise, the concentration is required to be

$$n \geq \lceil \frac{m}{h - \bar{e}} \rceil + 1 \tag{4}$$

Simulation Setup

Setup: With 9 agents moving in a 100×100 mission plane and strips with $h = 7.5$.

- Insufficient concentration does not guarantee convergence to a single cluster;
- Nodes do not collide as marked by the balls around the polytopes;
- Initial non-connected topology.

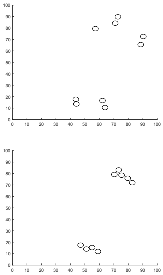


Figure: Initial configuration (top) and final (bottom).

Simulation Setup

Setup: With 20 agents moving in a 100×100 mission plane and strips with $h = 7.5$.

- Sufficient concentration ensures convergence to a single cluster;
- Nodes do not collide as marked by the balls around the polytopes;
- Initial non-connected topology;
- Collision avoidance determines the final shape.

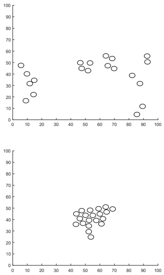


Figure: Initial configuration (top) and final (bottom).

Concluding Remarks

Contributions:

- We have proposed a consensus algorithm for disconnected networks.
- Using the SVOs for position estimate and checking intersection of overbounding balls, collision avoidance is guaranteed.
- In the journal version, we propose a general flocking algorithm that removes some of the assumptions.
- We have already extended these ideas to a fully decentralized algorithm.

References

D. Antunes, D. Silvestre, and C. Silvestre, "Average consensus and gossip algorithms in networks with stochastic asymmetric communications," in *50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC)*, Dec. 2011, pp. 2088–2093. DOI: 10.1109/CDC.2011.6161444.

D. Silvestre, J. P. Hespanha, and C. Silvestre, "Broadcast and gossip stochastic average consensus algorithms in directed topologies," *IEEE Transactions on Control of Network Systems*, vol. 6, no. 2, pp. 474–486, Jun. 2019, ISSN: 2325-5870. DOI: 10.1109/TCNS.2018.2839341.

D. Silvestre, P. Rosa, J. P. Hespanha, and C. Silvestre, "Set-consensus using set-valued observers," in *American Control Conference (ACC), Chicago, Illinois, USA*, Jul. 2015.

D. Silvestre, P. Rosa, J. P. Hespanha, and C. Silvestre, "Stochastic and deterministic fault detection for randomized gossip algorithms," *Automatica*, vol. 78, pp. 46 –60, 2017, ISSN: 0005-1098. DOI: http://doi.org/10.1016/j.automatica.2016.12.011.

The end

- Thank you for your time.

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