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Relative Affine Localization for Robust Distributed Formation Control

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***Abstract*—Multiagent systems have been widely researched and deployed in the industry for their potential to collectively achieve goals by distributing tasks to individual agents [1]–[4]. Formation control, one of the many applications of multiagent systems, aims at steering agents into a stable geometric pattern in space [3], [4]. There has been a variety of crafted distributed controllers in literature based on different dynamics that agents follow, and different variables that agents sense and control [5]. Affine formation control is brought to the spotlight where N agents in $\mathbb{R}^D$ converge to the target formation up to an affine transformation [6]. A more general scenario of affine formation control is the dynamic formation maneuvering problem where the target configuration is time-varying and the agents need to not only converge to the desired formation but also track the maneuvering pattern. This problem is addressed in [7] where a series of controller designs are introduced depending on the dynamics of the agents.**

One of the practical challenge for affine formation control is the awareness of relative positions of the neighbouring nodes, which may not be always available due to e.g. sensor malfunctioning and environmental interference. Missing relative positions entail an adverse impact on the control, which leads to a suboptimal or even unstable formation. In this work, we present relative affine localization (RAL) to estimate unavailable relative positions from the known ones in dynamic affine formation control settings. It is found that the global affine transformation parameters over the network can be locally estimated through a set of linear equations. As such, the missing relative positions of the neighboring agents can also be localized and then employed by the controller. We also conclude that in $\mathbb{R}^D$, D relative positions for each agent are sufficient for localization in general. Furthermore, a sequential Least Squares (SLS)-based adaptive filter across time is also implemented on top of RAL to track the underlying affine parameters and improve the performance. Fig. 1 shows the improvements in tracking error $\delta(t)$ when using RAL and SLS-based filtering. We also study two practical scenarios where the system is subject to a percentage of loss of relative positions and out-of-service agents, respectively. As a result, RAL is robust to these cases in terms of convergence and optimality. It is worth mentioning that this method applies to all the controllers introduced in [7] since they involve relative positions.

***Index Terms*—affine formation control, missing observations, sequential Least Squares**

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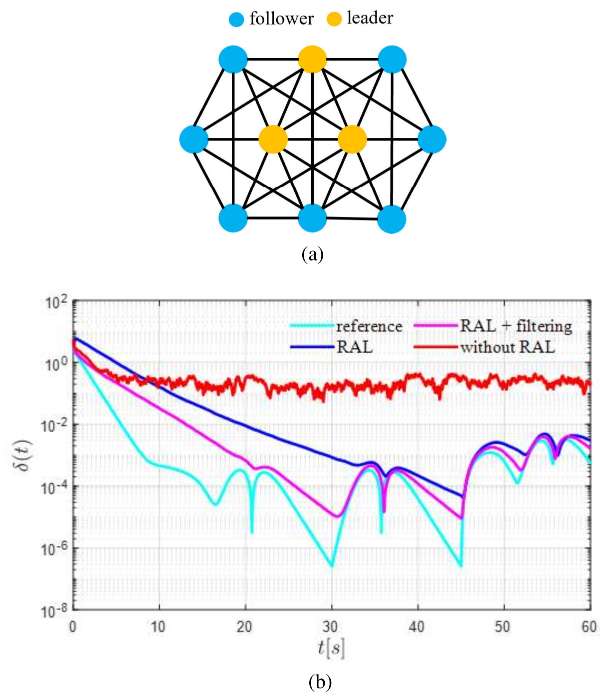

Fig. 1. (a) is the graph representation of formation where the vertices denote mobile agents and edges denote relative measurements. The time-varying target formation will be an affine transformation of the spatial locations of the vertices. (b) shows the mean tracking error $\delta(t)$ (difference of actual and target positions) across time t in seconds when only 3 relative positions are available per agent. The “reference” case is when all relative positions are available. This figure shows that without RAL the formation only converges suboptimally, but with RAL and SLS-based filtering the performance is much improved.

References

[1] S. Zhang, J. Zhou, D. Tian, Z. Sheng, X. Duan and V. C. M. Leung, ”Robust Cooperative Communication Optimization for Multi-UAV-Aided Vehicular Networks,” in IEEE Wireless Communications Letters, vol. 10, no. 4, pp. 780-784, April 2021, doi: 10.1109/LWC.2020.3043365.

[2] R. T. Rajan, et al., ”Applications and Potentials of Intelligent Swarms for magnetospheric studies,” in Acta Astronautica, Vol. 193, pp. 554-571, 2022, doi: 10.1016/j.actaastro.2021.07.046.

[3] H. Li, P. Xie and W. Yan, ”Receding Horizon Formation Tracking Control of Constrained Underactuated Autonomous Underwater Vehicles,” in IEEE Transactions on Industrial Electronics, vol. 64, no. 6, pp. 5004-5013, June 2017, doi: 10.1109/TIE.2016.2589921.

[4] J. Alonso-Mora, S. Baker and D. Rus. ”Multi-robot formation control and object transport in dynamic environments via constrained optimization,” in The International Journal of Robotics Research, vol. 36, no. 9, pp. 1000-1021, 2017, doi: 10.1177/0278364917719333.
[5] K. K. Oh, M. C. Park and H. S. Ahn, ”A survey of multi-agent formation control,” in Automatica, Vol. 53, pp. 424-440, 2015, doi: 10.1016/j.automatica.2014.10.022.
[6] Z. Lin, L. Wang, Z. Chen, M. Fu and Z. Han, ”Necessary and Sufficient Graphical Conditions for Affine Formation Control,” in IEEE Transactions on Automatic Control, vol. 61, no. 10, pp. 2877-2891, Oct. 2016, doi: 10.1109/TAC.2015.2504265.
[7] S. Zhao, ”Affine Formation Maneuver Control of Multiagent Systems,” in IEEE Transactions on Automatic Control, vol. 63, no. 12, pp. 4140-4155, Dec. 2018, doi: 10.1109/TAC.2018.2798805.