Designing the trajectory of microsatellite swarms from the macro-micro perspective

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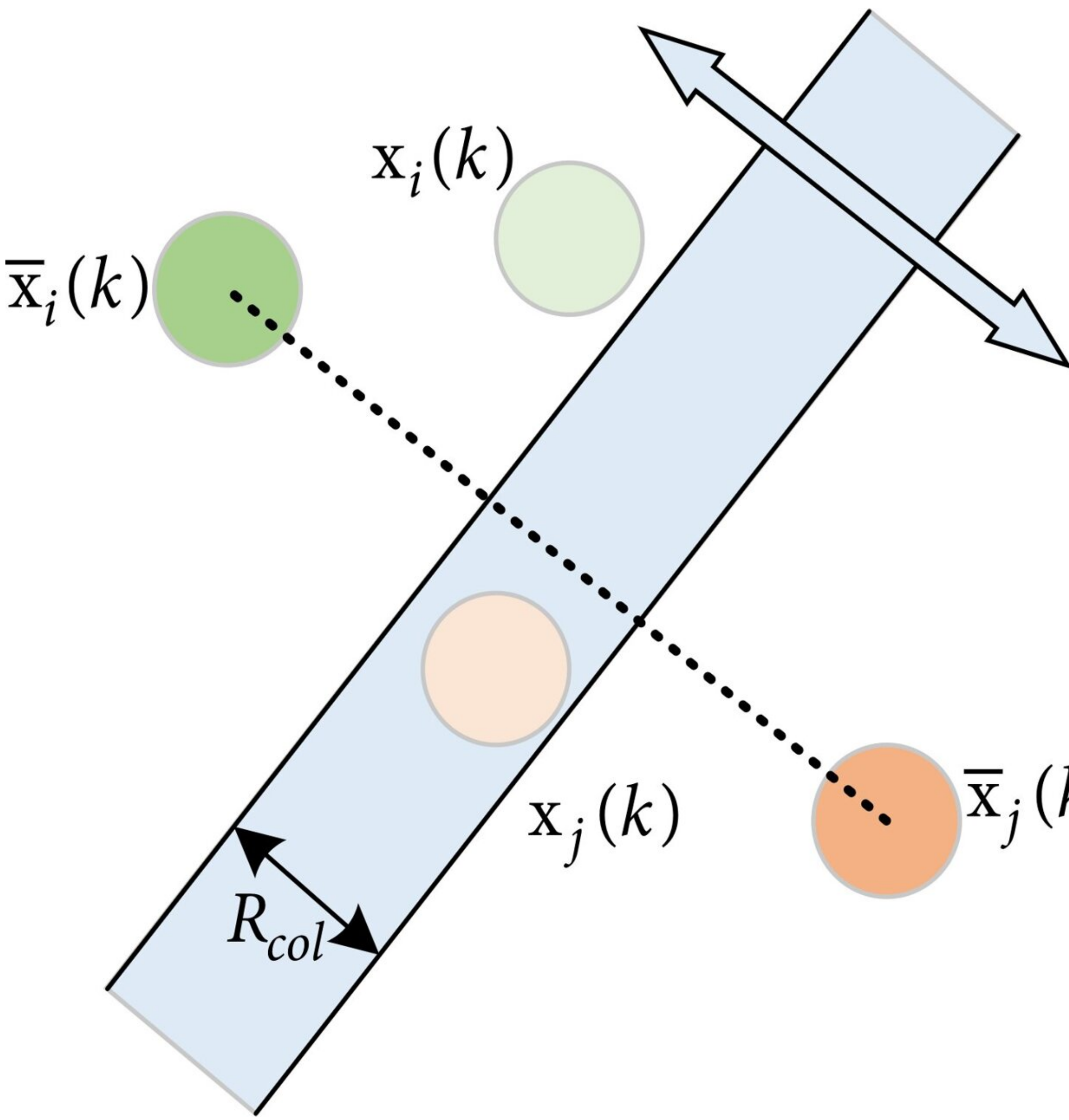

Diagram of collision avoidance between microsatellites. Credit: *Space: Science & Technology* (2022). DOI: 10.34133/2022/9802195

As an emerging multi-satellite cooperative flight mode, the microsatellite swarm has become an important future research issue for distributed space systems. It offers low cost, rapid response, and collaborative decision-making. To address the coordination of swarms for autonomous agents, a probabilistic guidance approach has been investigated, which contained sub-swarms with different mission objectives.

Probabilistic swarm guidance enables autonomous microsatellites to generate their individual trajectories independently so that the entire swarm converges to the desired distribution shape. However, it is essential to avoid crowding for reducing the possibility of collisions between microsatellites, which adds challenges to the design of the collision avoidance algorithm.

In a research paper recently published in *Space: Science & Technology*, Bing Xiao, from School of Automation, Northwestern Polytechnical University, proposed a Centroidal Voronoi tessellation (CVT) and Model Predictive Control (MPC) based synthesis method, aiming to achieve macro-micro trajectory optimization of a microsatellite swarm.

The author formulated the transfer model of swarm microsatellites in 3D space and introduced the probabilistic swarm guidance law. Afterwards, since it was essential to avoid crowding for reducing the possibility of collisions between microsatellites, the safety analysis of collision avoidance wad conducted based on finding the lower bound of the minimum distance between all microsatellites at any time.

To determine the collision-free guidance trajectory of each microsatellite from the current position to the target space, a collision avoidance algorithm was necessary. However, with high-level coordination that used the macroscopic models, collision-free trajectories were very hard to generate. Hence, the author presented a synthesis method, where the trajectory planning was divided into macro-planning and micro-planning.

Then, the author presented the details of macro-planning and micro-planning of the microsatellite swarm, respectively. In the Macro-planning of microsatellite swarm, the target position of each microsatellite was determined by the centroid generated through the CVT algorithm, and all microsatellites moved to the corresponding centroid until the algorithm converges.

The final distribution of the microsatellite swarm in the space was obtained according to the location of the centroid. In the Micro-planning of the microsatellite swarm, MPC was adopted to generate the optimal trajectories for each step and finally reached the specified position in the target cube.

Specifically, the author established the orbital dynamics model considering J_2 perturbation and implemented the convexification of collision avoidance constraints in the process of swarm reconfiguration. To achieve the real-time trajectory planning, model predictive control was introduced, which used a receding horizon to update the optimal trajectories based on the current state information. Significantly, the proposed method can not only realize collision avoidance of microsatellite swarm maneuvering at the macrolevel, but also provided optimal trajectories for each microsatellite of swarm individuals at the micro-level.

Finally, the numerical simulation was carried out to verify the proposed macro-micro trajectory planning method of microsatellite swarm. The author gave a virtual central microsatellite and designed a large-scale (300) microsatellite swarm with an omnidirectional flight configuration. The CVT algorithm was used to divide regions, and so as to determine the position of the microsatellites to be transferred at the next moment.

Then, one of the cubes was selected in the transfer process and performed CVT on it to determine the transfer position of the microsatellite. After 50 iterations, a stable configuration was obtained, and the position where the microsatellite moved at the next moment was determined. Due to the large scale of the microsatellite swarm, the process of achieving the final configuration required many transitions.

To verify the proposed trajectory optimization based on model predictive control, one of the microsatellites was selected from the initial point to the next desired target point at a certain moment. The individual microsatellites can reach the desired point well. After the desired point was reached, the next iteration would be carried out, and due to the influence of orbital dynamics, the microsatellite may not remain the target point without control constraints.

To make the mission of microsatellite swarm more practical, MPC was used in micro-planning to improve the performance of microsatellite swarm in terms of fuel consumption and resource utilization. Thus, simulation results about the collision-free guidance trajectory of microsatellites verified the benefits of the planning scheme, which accorded well with engineering practice.

More information: Xiwei Wu et al, Centroidal Voronoi Tessellation and Model Predictive Control–Based Macro-Micro Trajectory Optimization of Microsatellite Swarm, *Space: Science & Technology* (2022). DOI: 10.34133/2022/9802195