National Aeronautics and Space Administration

Robust Data-driven Vision-based multi-Spacecraft (RDVS) Guidance and Control

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Strategic Focus Area: Networked Distributed Systems

Objective: Develop a Robust Data-driven Vision-based multi-Spacecraft (RDVS) Guidance and Control framework. The vision+ CNN relative pose estimation using cameras is prone to failures. RDVS takes advantage of robust control synthesis to overcome this limitation and provides theoretical guarantees on mission performance for formation/reconfiguration applications.

We developed a simulation setup using Basilisk spacecraft dynamics simulator and Unreal (gaming) engine to produce photorealistic camera images. (Fig 1,2)
We replicated state of the art CNN based relative-pose estimation of a target spacecraft in ego-spacecraft's camera frame, which was used to characterize pose estimation uncertainties using set-based analysis techniques. (Fig 3,4)
We used LMI robust control design and passivity to ensure boundedness and invariance of the closed-loop trajectory. (Fig 5)

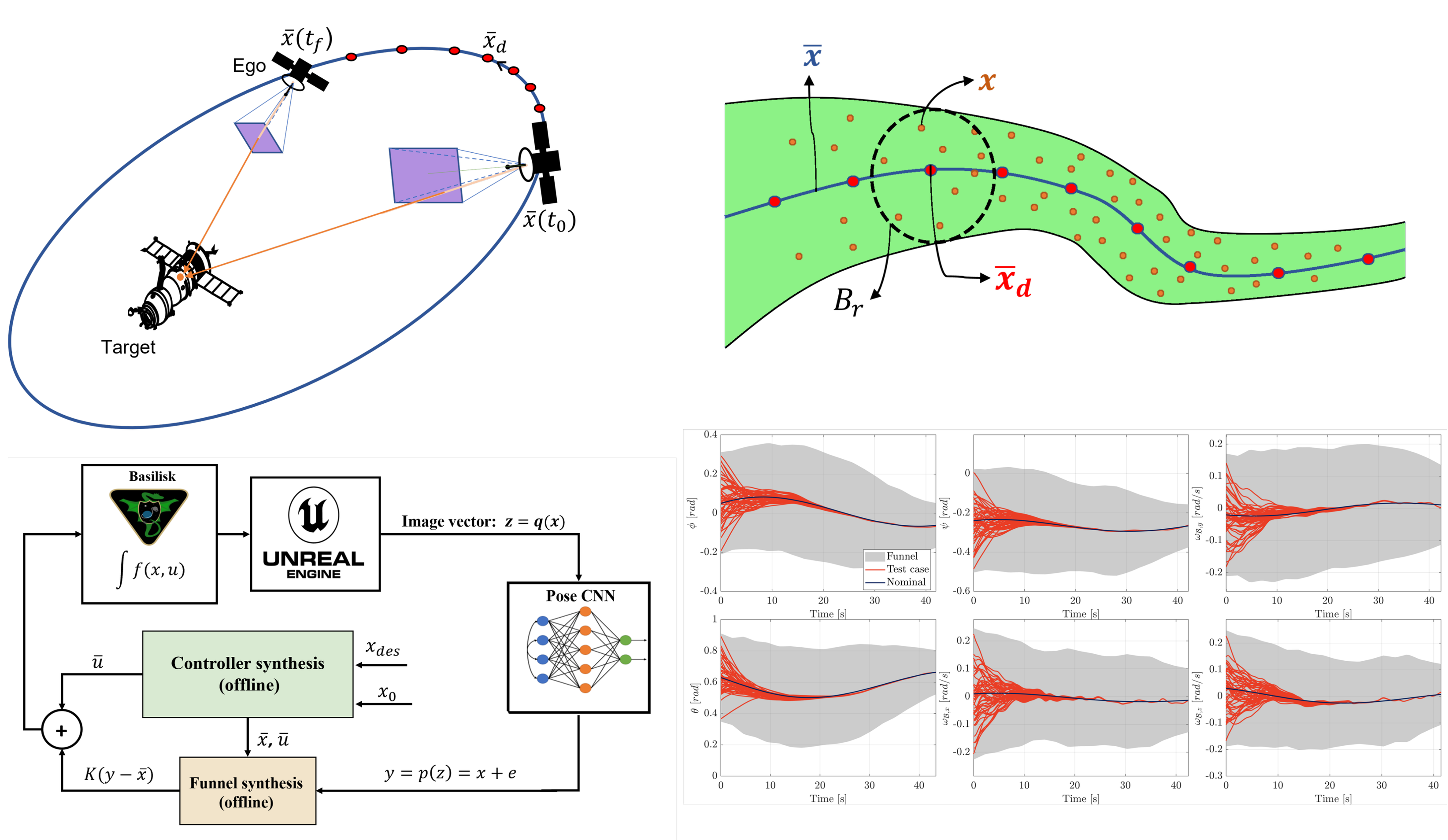

Fig 3: [Top left] is the tracking scenario on a flyby trajectory of the target.
[Top right] shows the error characterization around the nominal trajectory.
[Bottom left] demonstrates RDVS feedback control loop with Pose CNN estimating the relative position and orientation of the target spacecraft and [bottom right] the robust synthesis producing the control signals that are then fed to the spacecraft dynamics simulator.

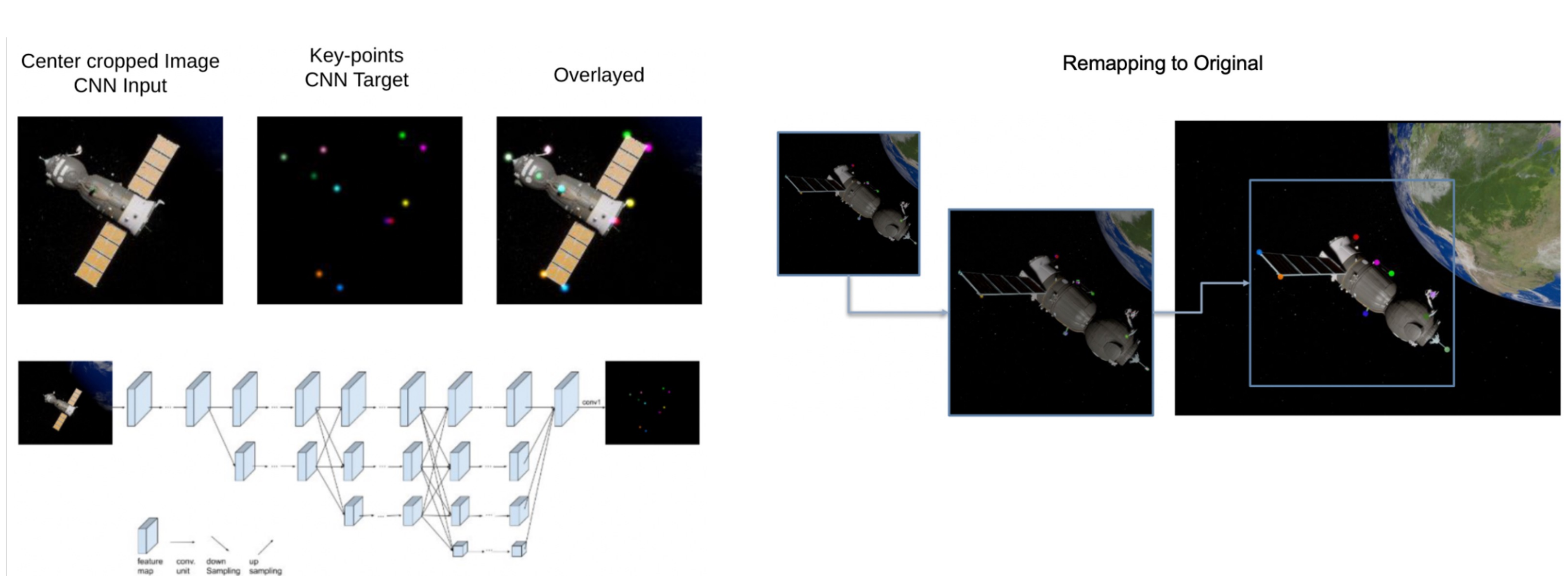

Fig 4: Pose estimation CNN maps the normalized image space to a set of keypoints, after a remapping to the original image space, positions of these keypoints along with camera parameters determine the pose (translation and rotation) of the target spacecraft. Effectively turning the vision+CNN to a metrology system for relative navigation.

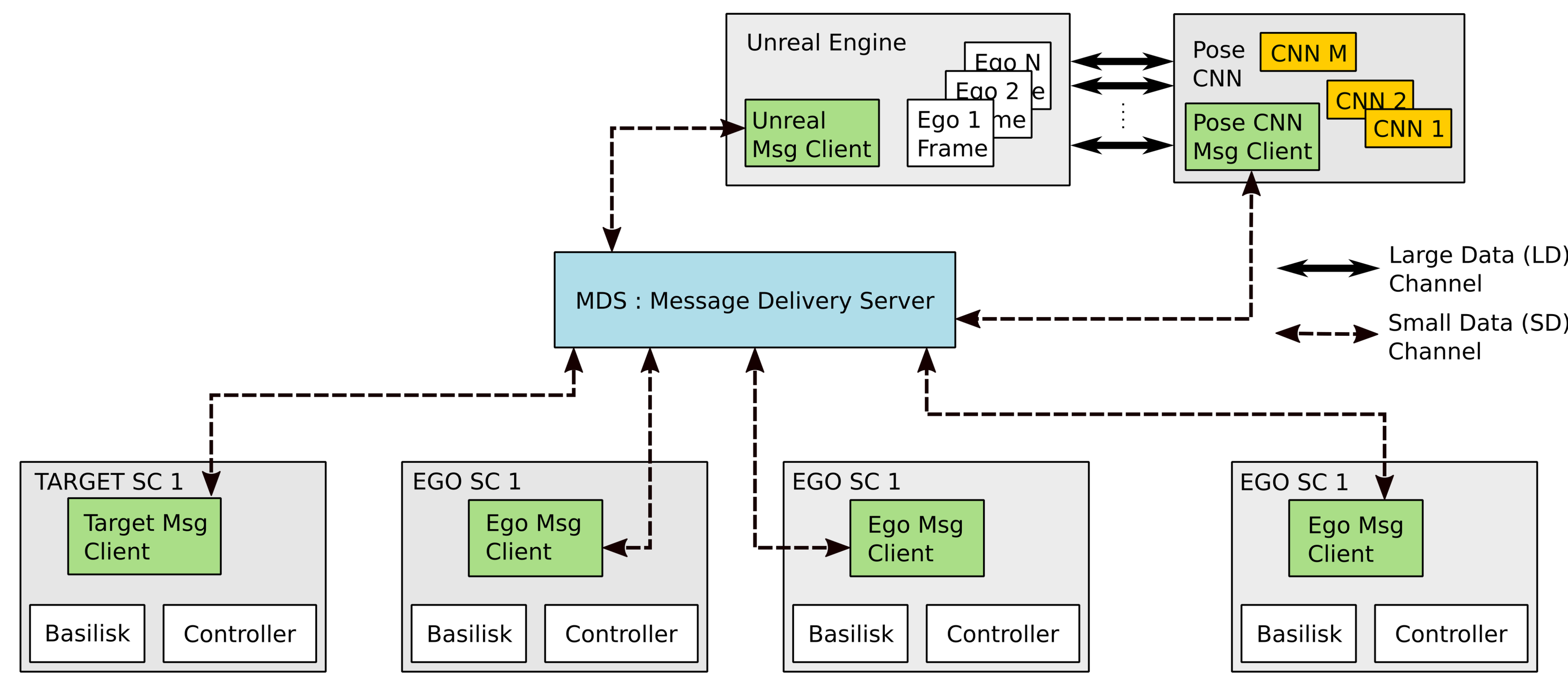

Fig 1: An end-to-end pipeline to generate high-fidelity imagery of the TargetSC from multiple EgoSC using Basilisk and Unreal software, and test our CNN-based pose estimation pipeline.

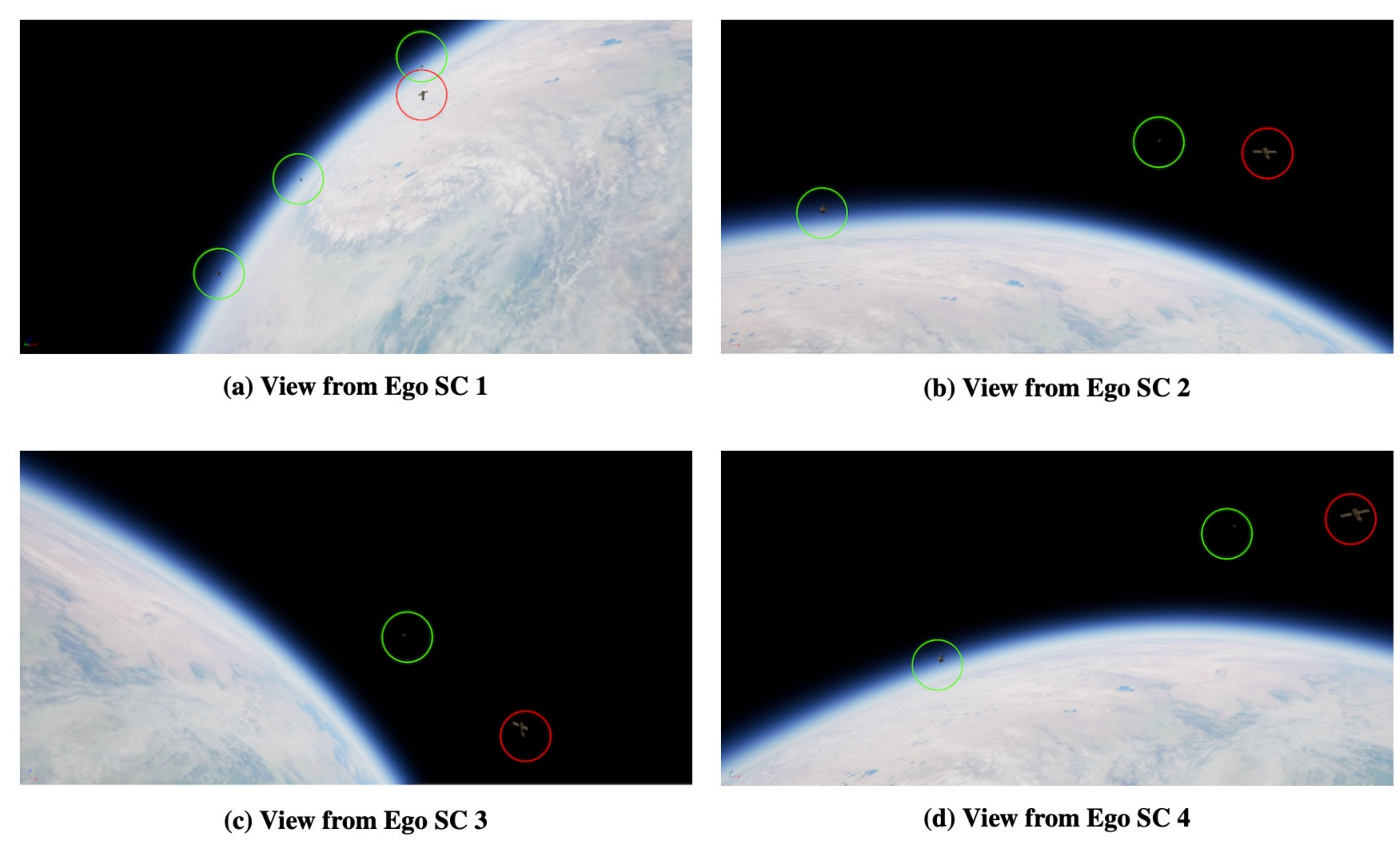

Fig 2: View of the target spacecraft (in red) from four Ego spacecraft (other Ego spacecraft in the field-of-view are shown in green).

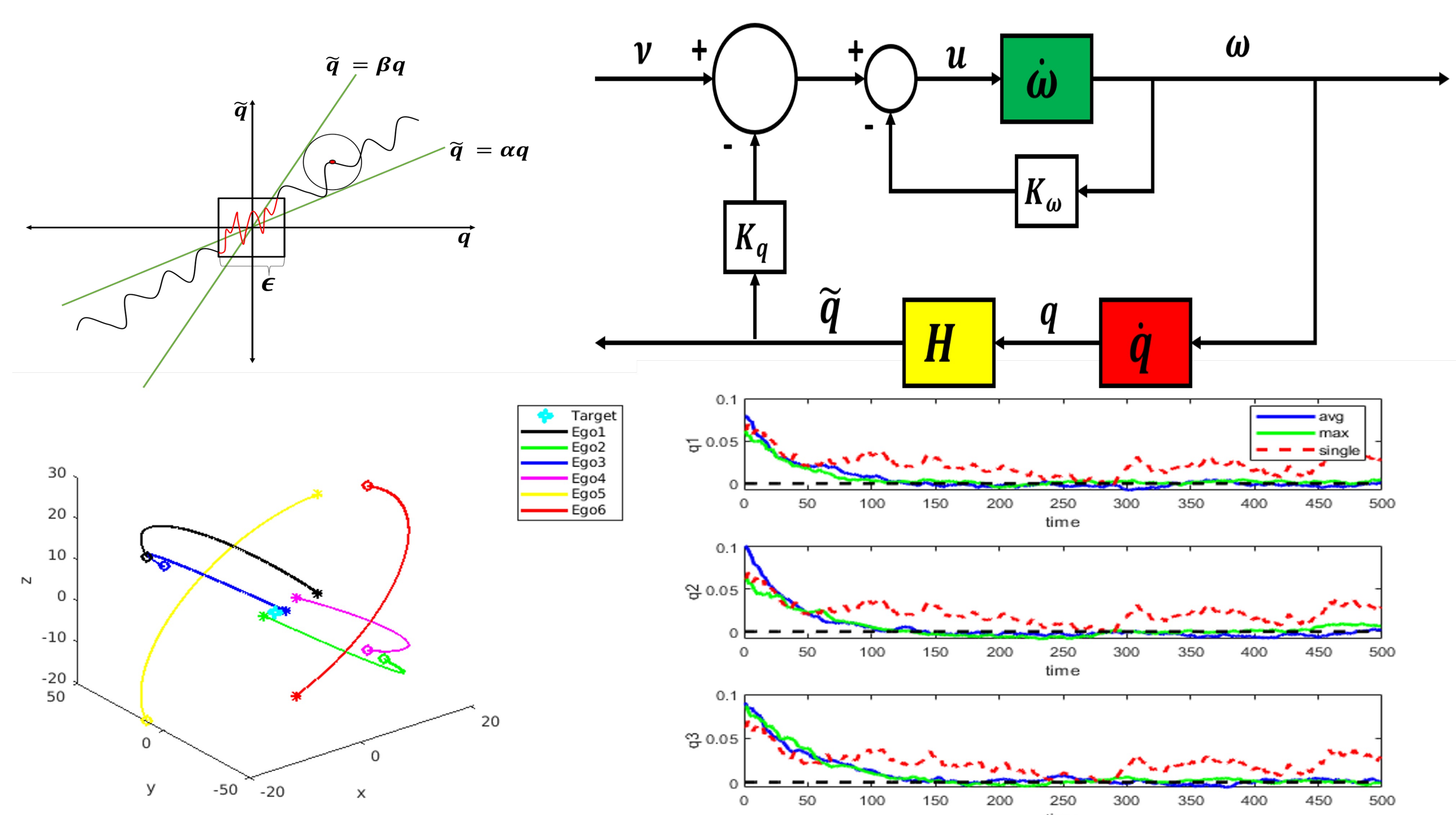

Fig 5: [Top-Left] sector bounded passivity-short model for CNN. We see that CNN output lies within a ball around the input in its general direction and can be bounded by sectors as shown.[Top-Right] Control system for passivity approach where an attitude rate system is interconnected with a passivity short system. [Bottom-Left] Multiple Ego satellites orbiting a Target [Bottom-Right] Tracking Attitude errors for Ego1, here we see better performance for average consensus(blue) and max consensus(green) compared to that of a single agent(red).

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Publications:

[A] J. Becktor, W. Seto, A. Deole, S. Bandyopadhyay, N. Rahimi, S. Talebi, M. Mesbahi, A. Rahmani, "Robust Vision-based Multi-spacecraft Guidance Navigation Control using CNN-based Pose Estimation", IEEE Aerospace Conference, Big Sky, MT, Mar. 2022. accepted.
[B] N. Rahimi, S. Talebi, A. Deole, M. Mesbahi, S. Bandyopadhyay, A. Rahmani, "Robust Controller Synthesis for Vision-based Spacecraft Guidance and Control", AIAA SciTech Guidance, Navigation, and Control (GNC), 2022.
[C] A. Deole, J. Becktor, W. Seto, S. Bandyopadhyay, N. Rahimi, S. Talebi, M. Mesbahi, A. Rahmani, "Multi-Agent Passivity-based Control for Perception-based Guidance," AIAA SciTech Guidance, Navigation, and Control, 2023.
[D] S. Bandyopadhyay, V. Gehlot, S. Kraisler, S. Talebi, A. Deole, J. Becktor, W. Seto, N. Rahimi, M. Mesbahi, A. Rahmani, "Vision-based Distributed Pose Estimation using a Spacecraft Constellation," AIAA SciTech Guidance, Navigation, and Control, January 2023.

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