Adaptive Artificial Potential Field Guidance for Vision-Aided Autonomous Docking with Uncooperative and Unknown Spacecraft

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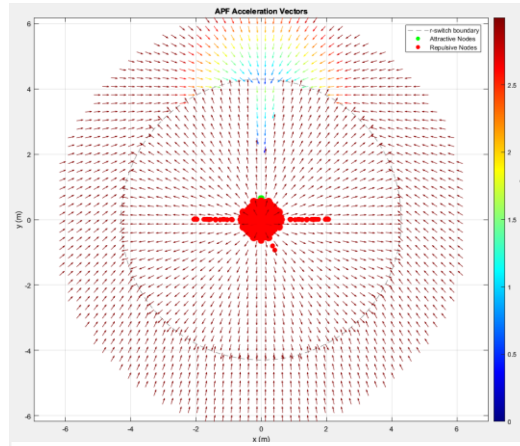
Introduction

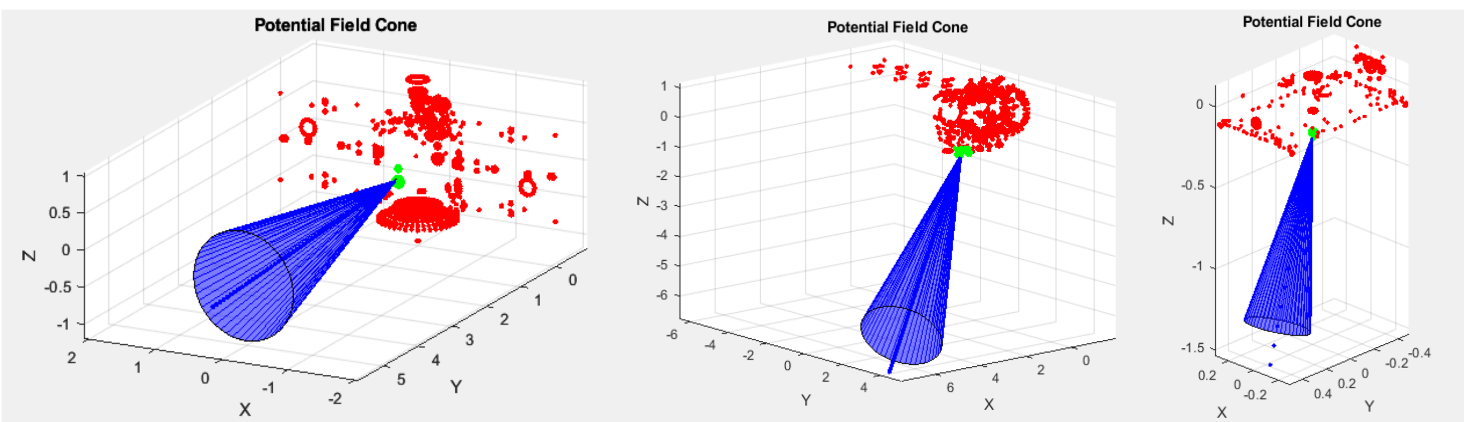
Autonomous docking with uncooperative spacecraft is vital for future on-orbit servicing and debris removal missions but remains challenging due to unknown geometries and the absence of navigation aids. Traditional guidance methods lack adaptability when operating near such targets. This work introduces an adaptive artificial potential field (APF) framework that integrates visual or LiDAR data to modify the potential field based on observed spacecraft geometry. The resulting geometry-adaptive approach corridor enables precise and reliable close-range docking without prior target knowledge, extending previous hardware-in-the-loop validation toward fully autonomous vision-aided operations.



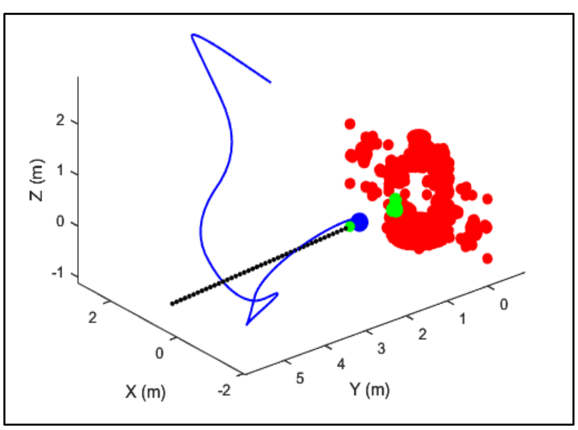
Artificial potential field static visualization

Methods

The algorithm begins with labeled points defining attractive and repulsive potential nodes. In the current implementation, point clouds are manually labeled, though future versions may employ a convolutional neural network (CNN) to identify potential docking sites automatically. The labeled point cloud is converted into a voxel grid to generalize spacecraft geometry and construct a protruding approach cone. The cone's centerline is designated as an attractive potential node line, guiding the chaser toward the docking position. A keep-out sphere is also generated around the target to prevent the artificial potential field from drawing the chaser too close, except when aligned within the approach corridor.



Approach cone and APF node visualization for several spacecraft geometries



Static RSO approach path

Conclusion

Initial testing demonstrates promising reliability across varying spacecraft geometries and sizes. However, the current rendezvous cost remains relatively high, at approximately 10–30 m/s ΔV. Ongoing work focuses on integrating reinforcement learning to optimize potential field utilization and reduce propellant expenditure. Additionally, current simulations are limited to short time spans with chemical propulsion–equivalent thrust levels. Future efforts will extend the simulation duration, evaluate performance under electric propulsion profiles, and assess robustness to incomplete point clouds.

References

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- J. Cutler, M. Wilde, A. Rivkin, B. Kish and I. Silver, "Artificial Potential Field Guidance for Capture of NonCooperative Target Objects by Chaser Swarms," in ASCEND 2021, 2021.
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