National Aeronautics and Space Administration

Spacecraft Attitude Path Planner Integration with the Basilisk Framework

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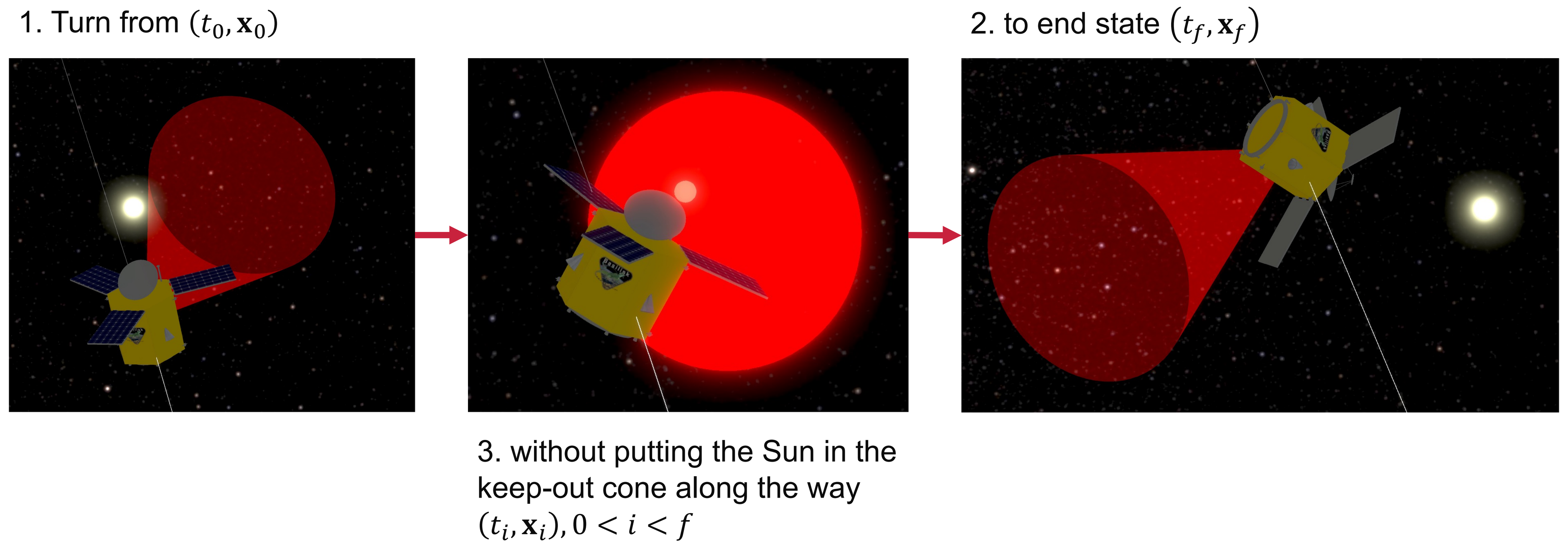
Objectives

The objective was to prototype an implementation of attitude path planning using components of the University of Colorado Basilisk astrodynamics simulation system [6] and assess the feasibility of using Basilisk in an attitude path planning algorithm benchmarking framework.

Background



Constraints have form $\theta = f(t, \mathbf{x})$, where ephemeris for separation angles is encoded in f, $\theta > 0$ is safe, and $\mathbf{x}$ is attitude state $\mathbf{x} = (\vec{\sigma}_N^B, \vec{\omega}_{B/N}, \vec{\alpha}_{B/N})$. Handles Type I (static) and Type III (dynamic) hard constraints from [3], keep-in and keep-out constraints from [8].

Planning algorithms solve the waypoint attitude planning problem statement:

Choose path

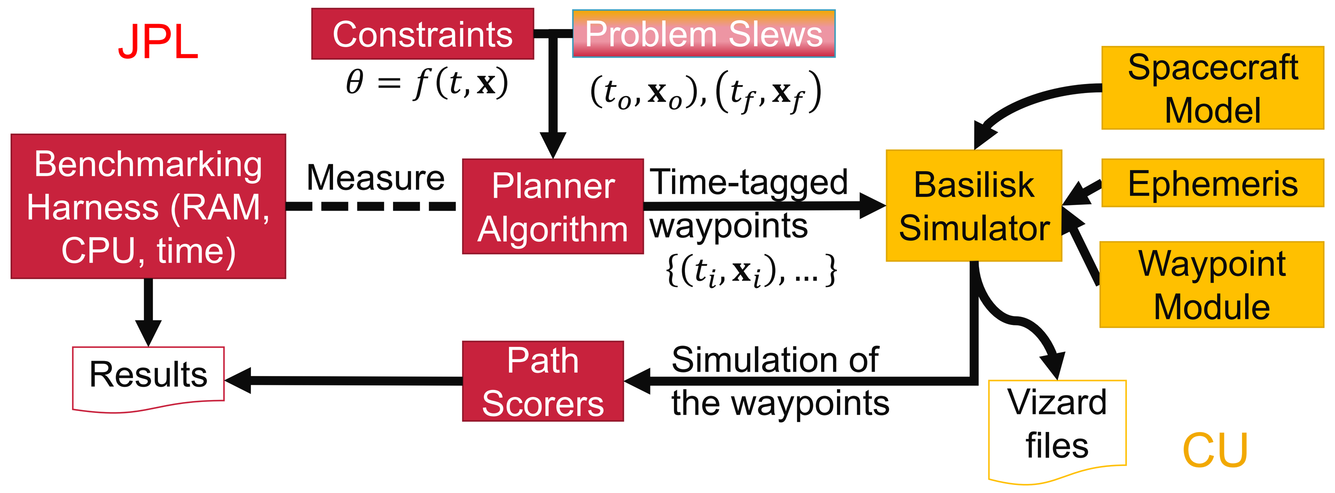
$\Pi = \{(t_0, \mathbf{x}_0), \ldots, (t_f, \mathbf{x}_f)\}$

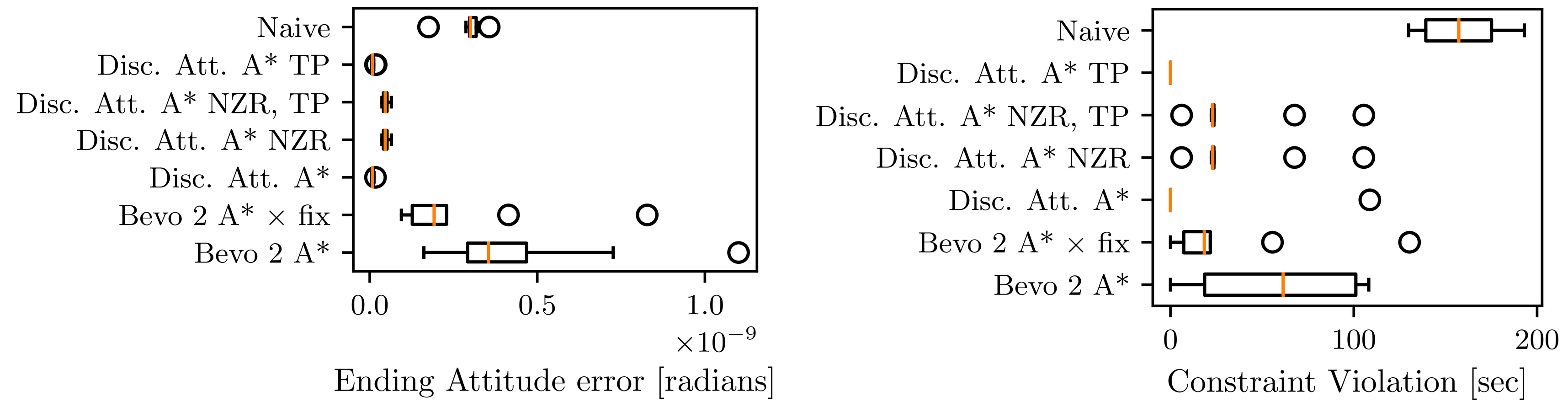
s.t. $\theta_i \geq 0 \; \forall t_i \in [t_0, t_f], \forall f_j \in F$

Algorithm families

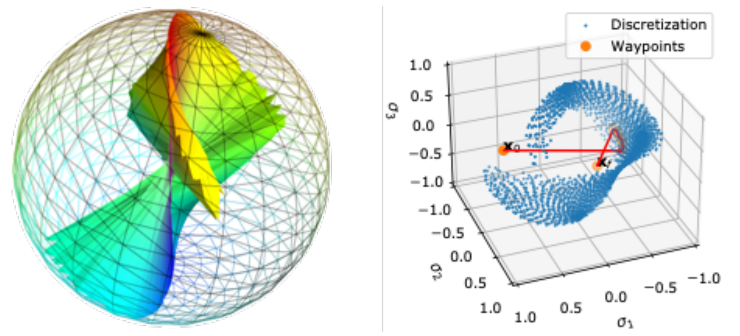
- Geometric [1]
- **Discretized A* [2,8] – the type we tested**
- Convex optimization, semidefinite programming [3]
- Feedback control laws [4]

Approach and Results





Kjellberg and Lightsey's 2015 Discretized Attitude A* algorithm [8] was more successful than their 2013 Bevo 2 A* algorithm [2] at both achieving the desired ending attitude (left) and complying with constraints (right). Nonzero rate waypoints (NZR) reduced the planner's effectiveness at achieving the goal pose and constraint-compliance. The 2013 algorithm's turn penalty (TP) had no effect on quality when applied to the 2015 algorithm.



The 2013 Bevo-2 attitude algorithm restricts planning to a 2D surface within the 3D attitude space (left), and its inaccurate distance metric produces poor paths (right).

Algorithm	Initialize [peak KiB]	Initialize [steady state KiB]	Solve [peak KiB]	Initialize [sec]	Solve [sec]
Naive	0	0	0.00 +- 0.0	0	0.000 +- 0.0
Discretized Attitude A* TP	14471.73	2911.24	108.77 +- 29.6	155.589	3.713 +- 2.3
Discretized Attitude A* NZR TP	14476.41	2922.39	106.94 +- 30.0	155.247	3.619 +- 2.0
Discretized Attitude A* NZR	14471.45	2910.94	107.96 +- 28.8	159.279	3.640 +- 2.0
Discretized Attitude A*	14471.58	2911.27	107.54 +- 32.5	153.264	3.627 +- 2.1
Bevo 2 A* cross-product fix	0	0	74.40 +- 218.8	0.003	0.203 +- 0.7
Bevo 2 A*	0	0	68.01 +- 181.6	0.004	0.138 +- 0.6

Significance/Benefits to JPL and NASA

- Better algorithm trade studies possible
- Potential for open algorithm design competitions
  - Spur future algorithm development
  - Grow the next generation of algorithm designers

Publications

[1] Riccardo Calaon, Michael Trowbridge and Hanspeter Schaub. "A Basilisk-based Benchmark Analysis of Different Constrained Attitude Dynamics Planners." In *2022 AIAA SciTech Forum* (accepted). Jan. 3-7, 2022.

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[2] Kjellberg, Henri C., and E. Glenn Lightsey. "Discretized constrained attitude pathfinding and control for satellites." *Journal of Guidance, Control, and Dynamics* 36.5 (2013): 1301-1309.
[3] Kim, Yoonsoo, Mehran Mesbahi, Gurkirpal Singh, and Fred Hadaegh. "On the constrained attitude control problem." In *AIAA Guidance, Navigation, and Control Conference and Exhibit*, p. 5129. 2004.
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[6] Kenneally, Patrick W., Scott Piggott, and Hanspeter Schaub. "Basilisk: a flexible, scalable and modular astrodynamics simulation framework." *Journal of Aerospace Information Systems* 17.9 (2020): 496-507.
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[8] Kjellberg, Henri C., and E. Glenn Lightsey. "Discretized quaternion constrained attitude pathfinding." *Journal of Guidance, Control, and Dynamics* 39.3 (2015): 713-718.

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