

Hybrid Path Planning for Long Lunar Traverse

Field Testing in a Lunar Analogue

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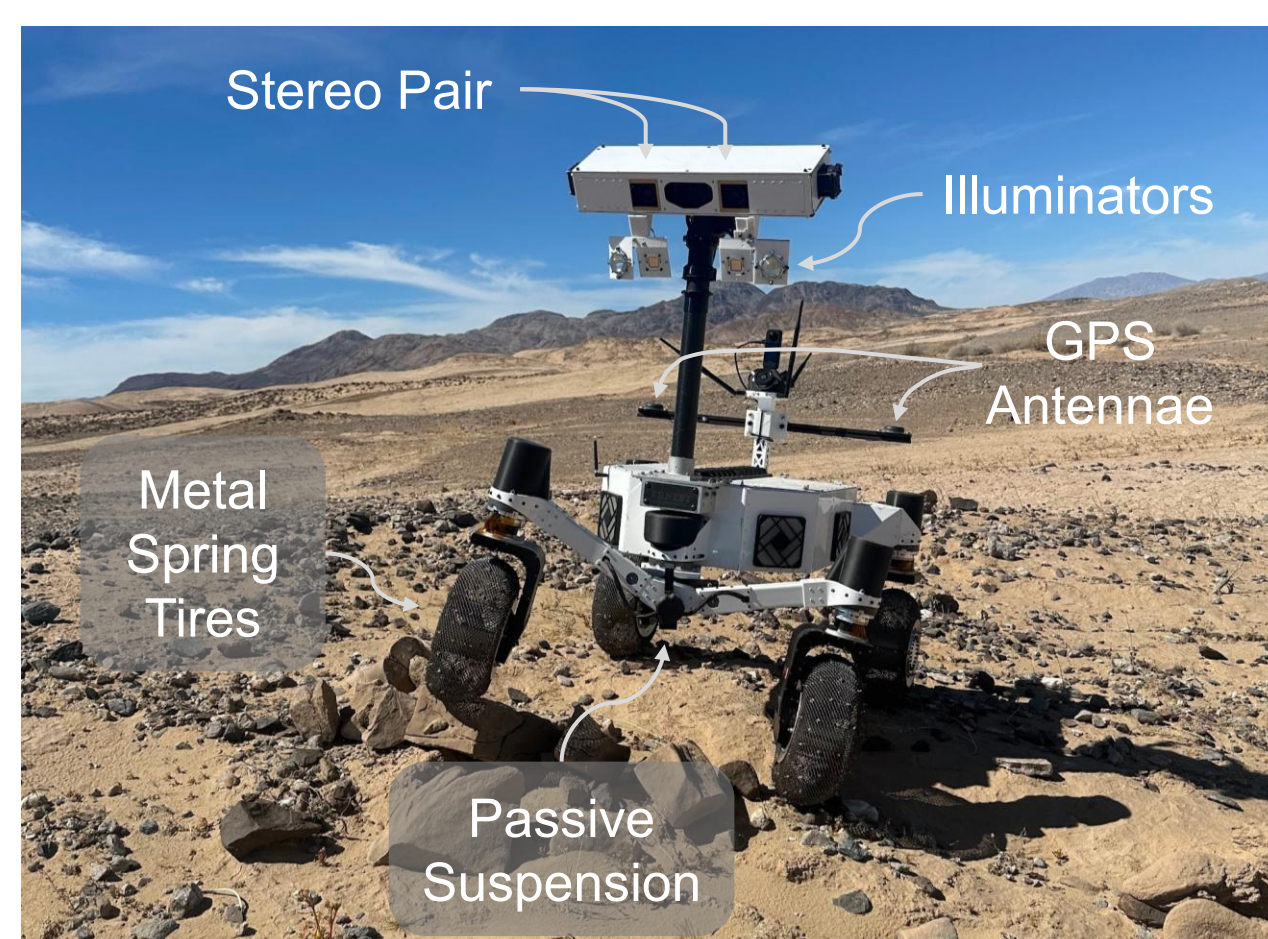
Overview

- Develop a multi-scale any-angle resolution-complete path planner based on the fast marching method (FMM) [1]
- Produce a continuous time-to-goal (TTG) field over the entire area of operation with a coarse grid
- Recompute times-to-goal with a fine grid within the local map based on perceived terrain
 - Gradient descent of the TTG produces a smooth path
- Drive 9.57 km in closed-loop testing in the desert

Problem Context

- Endurance mission concept would drive 2700 km across the Aitken Basin autonomously collecting rock samples
- Mission would require intervention-free drives > 20 km
- Lunar depth elevation maps (DEMs) of the basin vary in resolution from 5 - 50 m / pixel
- Lunar global localization every 2 km
- Global planning is expensive
 - Hybrid planning precomputes times-to-goal on the ground and computes local times-to-goal on the rover

ERNEST (Exploration Rover for Navigating Extremely Sloped Terrain)

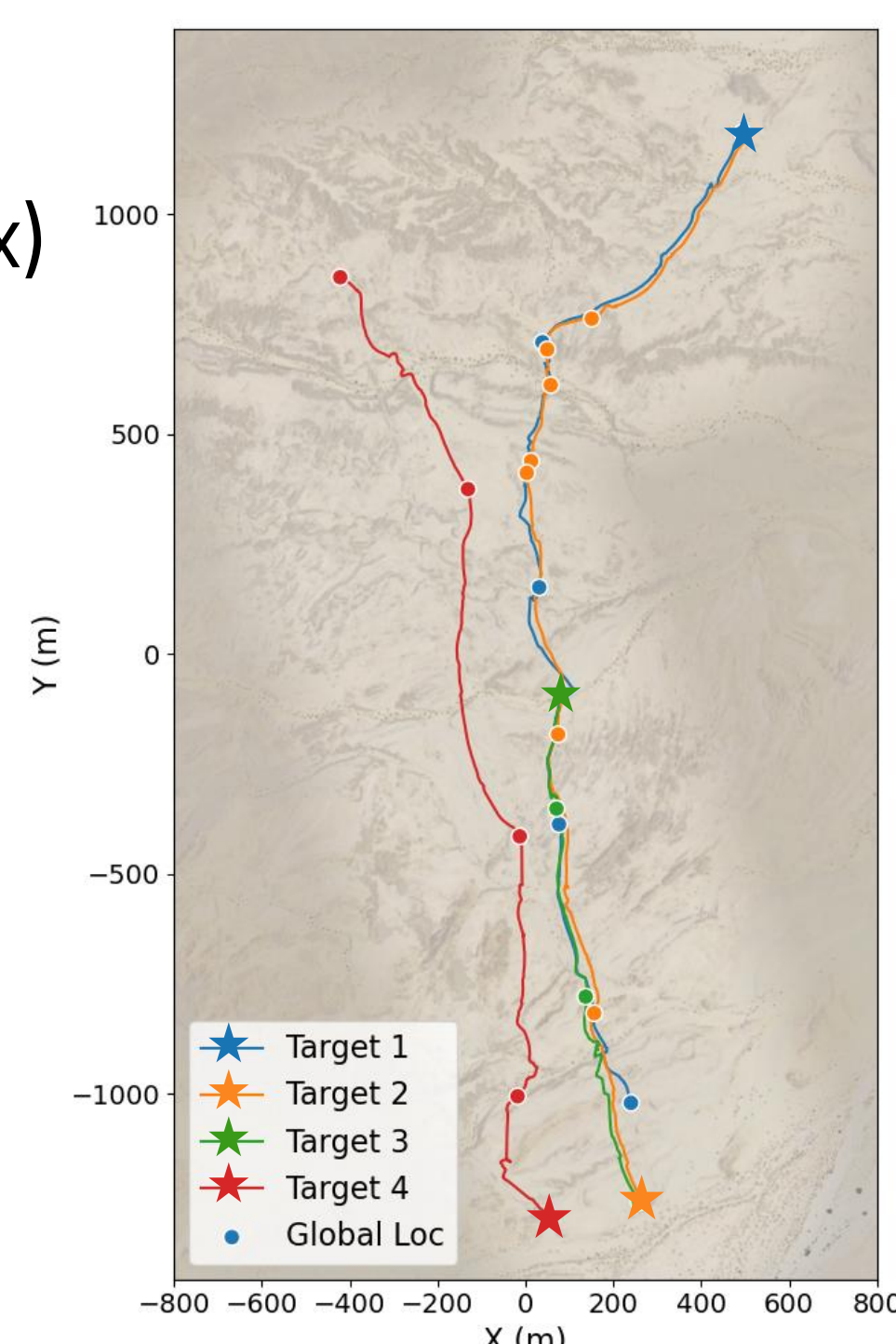


- Stereo range: 7 m
- Forward speed: 0.28 m/s
- Battery life: 2.5 hrs
- GPS-INS for ground truth
- 360° camera for logging
- Target < 18° slope

Results

- Total drive time: 13.316 hrs
- 0.11% of time > 18° slope (22.3° max)
- 19 global localization updates
- Local obstacles increase drive length by < 10%
- 1.5 km between interventions

Science Target	Ground Truth Path Length	Global Path Length	Ratio
Target 1	2747 m	2593 m	1.059
Target 2	2987 m	2751 m	1.086
Target 3	1299 m	1222 m	1.063
Target 4	2540 m	2397 m	1.059



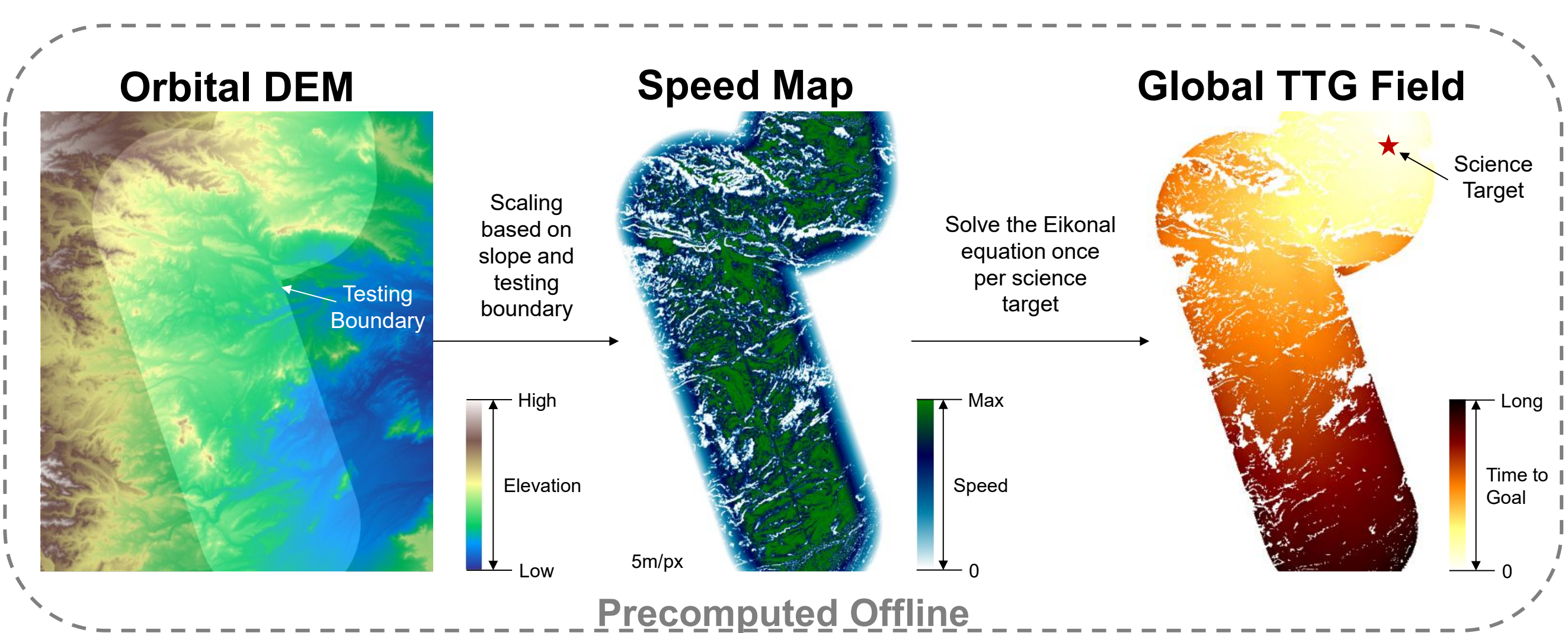
References

- [1] Gómez, J. V. *Fast marching methods in path and motion planning: Improvements and high-level applications*. Ph. D. thesis, University Carlos III Madrid, Spain 2015.
- [2] J. A. Sethian, "Fast Marching Methods," SIAM Review, vol. 41, no. 2, pp. 199–235, 1999

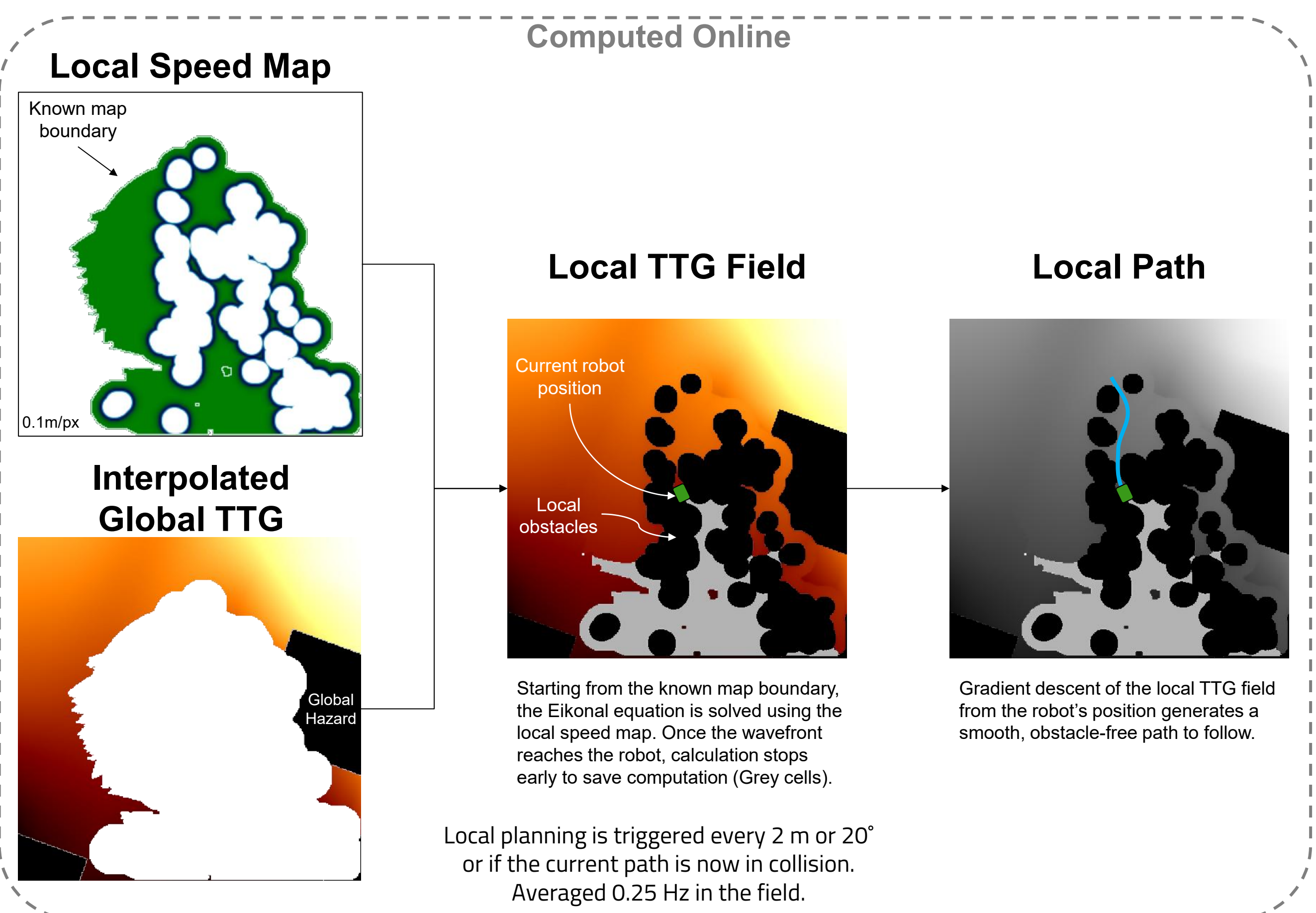
Fast Marching Method Background

- $O(n \log n)$ numerical approximation to the Eikonal Equation [2] of wave propagation: $\|\nabla T(x, y)\| = \frac{1}{|v(x, y)|}$
- $T(x, y)$ is the time to reach a position from the goal
- $|v(x, y)|$ is the speed, an input, at that location

Algorithm Details



- Traversability layer generates a local speed map
- Seeds FMM with interpolated values from the global TTG on the map boundary



Future Work

- Trigger global localization based on gates in global TTG field
- Sensitivity analysis on global resolution
- Spatiotemporal global planning to avoid changing shadows

Conclusion

- Interpolation of a low-resolution time-to-goal field guides rovers around global hazards without a pre-defined path
- Multi-resolution planner benefits from precomputed global information and reactions to local hazards