Research Project

Extending Quantum Annealing Optimization to Earth–Moon Transfers

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Summary

This project proposes to extend Carbone et al.'s pseudospectral QUBO transcription framework [1], originally applied to Earth–Mars low-thrust transfers, to optimize Earth–Moon trajectories via quantum annealing (QA). The Earth–Moon system presents unique challenges due to its proximity, gravitational perturbations, and the frequent use of multi-revolution, low-energy transfers.

By adapting the transcription method to this specific dynamical context and leveraging the capabilities of D-Wave's new Advantage 2 system, featuring enhanced coherence and connectivity, we aim to test the effectiveness of the recently released nonlinear hybrid solver for realistic mission planning. This research seeks to bridge the gap between classical optimal control and practical quantum-based methods, advancing the state-of-the-art in quantum computing in aerospace engineering.

Furthermore, inspired by the classical Thomson's problem, this project leaves open the possibility of extending quantum annealing applications to finding the optimal satellite distribution for evenly covering the Earth. Other potential applications of quantum annealing in aerospace optimization problems remain open for future studies, making this research a contribution toward broader investigations.

Objectives

1. Formulate the Earth–Moon transfer as a discrete QUBO using pseudospectral method.
2. Implement and benchmark on D-Wave Advantage 2 non-linear hybrid solver, evaluating coherence and connectivity improvements.
3. Compare QA solutions with classical optimization.
4. Identify scalability limits and propose improvements in transcription or solver configuration.
5. Quantum annealing approaches to Thomson's problem.

State of the Art

Quantum annealing for trajectory optimization has been demonstrated for an Earth–Mars mission, using pseudospectral methods to transcribe low-thrust dynamics into a QUBO and solving via D-Wave hybrid solvers [1]. Recent hardware (Advantage 2) offers higher qubit connectivity and non-linear annealing schedule [2]. Similarly, the use of simulated annealing for geometric optimization on spheres, such as satellite constellation distribution problems inspired by Thomson's problem, has received increased attention [3]. These developments suggest a growing interest in quantum-enhanced methods across different aerospace optimization tasks, laying the foundation for further investigation.

Training and Research Aspects

This project is designed to strengthen both my theoretical and practical competencies in advanced astrodynamics and quantum computing. On the training side, it will enhance my understanding of Earth-Moon trajectory dynamics, optimal control transcriptions, and hybrid quantum-classical optimization workflows. It will also deepen my familiarity with state-of-the-art quantum annealers, their programming models, and limitations.

From a research perspective, this work aims to expand the application of quantum annealing in aerospace engineering, pushing its boundaries beyond interplanetary missions to cislunar transfers and Earth-orbiting satellite distributions. The project seeks to contribute novel methodologies to the emerging field of quantum computing applied to aerospace.

Research Plan

Months 1–2: Develop and validate the pseudospectral QUBO model for Earth–Moon dynamics, including boundary conditions and control constraints.

Months 3–4: Execute experiments on D-Wave Advantage 2 using nonlinear hybrid solver; collect data on solution quality, annealing schedules, and runtime.

Months 5–6: Analyze results, perform classical optimizer comparisons, refine the QUBO encoding as needed, and carry out an initial exploration of formulations for the distribution of satellites orbiting the Earth, inspired by Thomson's problem.

References

[1] Federico De Grossi, Andrea Carbone, Dario Spiller, Daniele Ottaviani, Riccardo Mengoni, and Christian Circi. ”Transcription and optimization of an interplanetary trajectory through quantum annealing”. *Astrodynamics. Volume 9, pages 195–215, (2025)*

[2] Web de D-wave: https://www.dwavequantum.com

[3] Y. Xiang, D. Y. Sun, W. Fan, X. G. Gong. ”Generalized simulated annealing algorithm and its application to the Thomson model”. *Physics Letters A 233 (1997) 216-220*