Autonomous closed-loop guidance using reinforcement learning in a low-thrust, multi-body dynamical environment*

*Reinforcement Learning Course Project Report

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Abstract—Onboard autonomy is an essential component in enabling increasingly complex missions into deep space. In nonlinear dynamical environments, computationally efficient guidance strategies are challenging. Many traditional approaches rely on either simplifying assumptions in the dynamical model or on abundant computational resources. This research effort employs reinforcement learning, a subset of machine learning, to produce a 'lightweight' closed-loop controller that is potentially suitable for onboard low-thrust guidance in challenging dynamical regions of space. The results demonstrate the controller's ability to directly guide a spacecraft despite large initial deviations and to augment a traditional targeting guidance approach. The proposed controller functions without direct knowledge of the dynamical model; direct interaction with the nonlinear equations of motion creates a flexible learning scheme that is not limited to a single force model, mission scenario, or spacecraft. The learning process leverages high-performance computing to train a closedloop neural network controller. This controller may be employed onboard to autonomously generate low-thrust control profiles in real-time without imposing a heavy workload on a flight computer. Control feasibility is demonstrated through sample transfers between Lyapunov orbits in the Earth-Moon system. The sample low- thrust controller exhibits remarkable robustness to perturbations and generalizes effectively to nearby motion. Finally, the flexibility of the learning framework is demonstrated across a range of mission scenarios and low-thrust engine types.

Index Terms—Reinforcement learning-based, computationally efficient closed-loop control enables autonomous low-thrust guidance in complex deep-space missions, showcasing flexibility across diverse scenarios without relying on explicit dynamical models.

I. INTRODUCTION

This document is a model and instructions for LATEX. Please observe the conference page limits.

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- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0 , and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
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 word alternatively is preferred to the word "alternately"
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An excellent style manual for science writers is [7].

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Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you

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a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE I
TABLE TYPE STYLES

Table	Table Column Head		
Head	Table column subhead	Subhead	Subhead
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^aSample of a Table footnote.

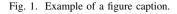


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ACKNOWLEDGMENT

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REFERENCES

Please number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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