

Title: Transformative Modeling of Spacecraft Thermal Control Systems using Physics-Informed Neural Networks

Subtitle: Innovative Approach for Enhanced Efficiency and Reliability in Space Missions

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Introduction:

Spacecraft thermal control systems (TCSs) are fundamental to the success of space missions, ensuring that onboard components operate within specified temperature ranges. Traditional modeling techniques for spacecraft TCSs often rely on deterministic physics-based models or empirical relationships, which may lack the flexibility to adapt to changing mission parameters and often suffer from limitations in accuracy, particularly in capturing complex thermal interactions. These limitations can lead to suboptimal spacecraft designs and compromised mission success rates. In response to these challenges, this research proposes an innovative approach using Physics-Informed Neural Networks (PINNs) for high-fidelity modeling of spacecraft TCSs.

Background:

Spacecraft TCSs face a range of thermal challenges, including managing heat generated by onboard electronics, regulating temperatures in various environments, and mitigating thermal stresses during different mission phases. Current modeling techniques typically involve deterministic physics-based models or empirical correlations, which may struggle to capture the intricacies of thermal behavior accurately. Additionally, these methods often require extensive computational resources and may not easily accommodate the integration of multiple interacting thermal phenomena.

Proposed Approach:

The proposed approach leverages the capabilities of PINNs to overcome the limitations of traditional modeling techniques. PINNs integrate fundamental physics principles into neural network architectures, allowing for the accurate representation of complex thermal behavior within spacecraft TCSs. By embedding physical laws directly into the neural network framework, PINNs offer a unified approach to modeling that can capture the interactions between different thermal phenomena with high fidelity.

Technical Objectives:

The research outlines several key technical objectives to achieve the proposed approach's goals. These objectives include the development of a robust PINN framework for TCS modeling, training and validation of PINN-based models using thermal data, integration of multiple thermal phenomena within the models, demonstration of proof-of-concept results showcasing the efficacy and advantages of the proposed approach and delivering a functioning prototype that demonstrates the potential to meet the performance goals of the software.

Expected Benefits:

The adoption of PINNs for spacecraft TCS modeling is expected to yield significant benefits for space missions. These include improved modeling accuracy, enhanced flexibility to adapt to changing mission parameters, reduced computational costs, and the ability to capture complex thermal interactions more comprehensively. By enabling more accurate predictions of temperature distributions, thermal gradients, and transient responses within TCS components, PINNs can facilitate better spacecraft design optimization and operational efficiency.

Relevance to NASA Missions:

The proposed research offers innovative solutions to optimize spacecraft TCS designs, addressing critical gaps in current modeling techniques. Moreover, the proposed approach holds relevance for various NASA missions, including lunar exploration, Mars exploration, SmallSats/CubeSats, and future science missions, by ensuring optimal thermal management and protection of spacecraft components.

Conclusion:

In conclusion, the proposed approach of using PINNs for high-fidelity modeling of spacecraft TCSs represents a transformative advancement in the field of space mission optimization. By integrating physics principles with advanced machine learning techniques, PINNs offer a promising solution to address the challenges associated with traditional modeling techniques. The research aims to deliver comprehensive reports detailing the development, implementation, and validation of PINN-based models for spacecraft TCSs, demonstrating their efficacy and potential to enhance mission success rates and operational efficiency in space exploration endeavors as well as a functioning prototype that demonstrates the potential to meet the performance goals of the software.