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LEARNING COMPLEX SPACE MANIPULATOR DYNAMICS USING NEURAL ODES: A DISTURBANCE-ROBUST FRAMEWORK

Abstract

This paper presents a novel framework for learning and predicting the dynamics of free-floating space manipulators subject to external disturbances using Neural Ordinary Differential Equations (Neural ODEs). While traditional dynamics modeling approaches struggle with uncertainties and disturbances, our method integrates physics-based dual quaternion dynamics with Neural ODEs to capture complex nonlinear behaviors and adapt to varying disturbance conditions. The framework employs a progressive training strategy across multiple time horizons and implements a specialized network architecture with skip connections to enhance stability and prediction accuracy. The proposed approach is validated on a two-link space manipulator system under both sinusoidal and random disturbance profiles. Our implementation utilizes a four-layer neural network with a composite loss function incorporating position, velocity, and momentum conservation terms. Results demonstrate robust prediction capabilities with position tracking errors below 0.1% and stable prediction of coupled base-manipulator motion across 10-second horizons. The framework shows effectiveness in handling both periodic and stochastic external disturbances while maintaining conservation of momentum in disturbance-free conditions. This work represents a significant advancement in space robotics by providing a learning-based framework that maintains physical consistency while adapting to uncertain dynamics, essential for future autonomous space debris removal missions.