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IDENTIFYING UNDERLYING STRUCTURES IN ASTRODYNAMICS WITH THE DATA-DRIVEN HAVOK ANALYSIS

Abstract

In recent years, many scientific and engineering fields have seen the application of new methodologies based on Machine Learning or Data Processing Algorithms to tackle present and past problems with varying degrees of success. These efforts also include techniques coming from the Fluid Dynamics field to study Dynamical Systems, trying to identify the structure and the dynamics behind highly complex and chaotic systems that have no closed solution, or no governing equations, with the use of spatio-temporal measurements of the system. HAVOK (Hankel Alternative View Of Koopman) is one of such methodologies, utilizing different dimensional measurements of the system's state to build a diffeomorphic model and then using Dynamic Mode Decomposition (DMD) or Sparse Identification of Dynamics methods to reconstruct the original system. In order to model the chaotic behaviour of the dynamical systems, HAVOK treats the least energetic mode of the system as a control input term. In these reconstructed systems, different dynamical structures and events have been recognized in the literature that aid in the characterization, modelling and even controlling of the systems using linear algorithms.

In this paper we apply HAVOK to different trajectories in the Solar System and different measurements of Dynamical Systems, and re-construct them to retrieve the dynamics from data and the application of time-delayed coordinates. We compare the results from various measurements of the same system and from different systems to identify differences in the applicability of the algorithm. We find the linearized representations of the systems and evaluate their accurateness with respect with the original system. From the HAVOK-obtained linearized systems we try to isolate sections of the trajectories and identify important behaviours present in the original systems (e.g. changes in main body orbited or third-body perturbations) and we try to find equivalences with classical dynamical systems theory structures like periodic orbits, resonant orbits and stability. We realize a comprehensive analysis of trajectories in the Earth-Moon system to benchmark the technique against current trajectory design methods and try to identify transmit mechanisms and analyze different types of trajectories (e.g. ballistic lunar transfer from L2 side). Finally, we evaluate the feasibility of this method as-is, compare the results with other techniques

(substituting linear regression models for deep learning networks), and gauge the possible applicability in other challenges in the field of astrodynamics.