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Automatic mode tracking for flight dynamic analysis using a spanning algorithm

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ABSTRACT

Identifying and tracking dynamic modes in a multi-dimensional parameter space is a problem that presents itself in many engineering disciplines. In a flight dynamics context, the dynamic modes refer to the modes of motion obtained from a linearisation of the aircraft system about a known operating point. Typically dynamic results derived from these linear models are unsorted, where mode indices are unrelated from one operating point to the next. When varying the parameters, or in this case operating point, difficulties in automating the process of relating modes from a linear system derived at one parameter set to the next exists. This paper builds on the work in tracking modes in a structural context, using the Modal Assurance Criterion (MAC) to numerically relate modes from two comparable linear systems. The (MAC) is deployed within a spanning algorithm to discover and identify all modes within all conditions, with their relationship to adjacent/neighbouring conditions. This is tested on a 1-, 2- and 3-dimensional parameter space, twelve state system.

1. Introduction

For a nonlinear dynamic system, the modal characteristics and shapes are likely to vary considerably throughout the operational envelope of the system. Observing how specific modes evolve in a system can be beneficial when analysing the stability properties, and in the development of controllers. The linear dynamic properties of these nonlinear systems are typically obtained by linearising the system about an operating point, and using linear systems analysis methods, the modal properties can be extracted. However, the analysis method typically generates unsorted eigenstructures of the system dynamics, such that there is no relation between the data from one operating condition to another.

Identifying and tracking modes is also a problem in structural dynamics. Structural dynamicists are concerned with, for example, validating a model to represent one or more modes of a system from experimental data, at various operating points. The Modal Assurance Criterion (MAC) has been widely used to address problems in structural dynamics and vibrations [20], providing a measure to correlate modes from two comparable systems. In this case, the system is a structure, where the system dynamics of a model is being compared to the experimental data at the equivalent operating point. It is conceivable that using the same algorithm for the model at varying operating points, the dynamic results can be compared to relate the modes from one operating point to another.

In this paper, the MAC is applied to adjacent/neighbouring (graph theory) operating points, to ascertain dynamic correspondence, and track a mode through this parameter space. The paper deploys this MAC in a spanning algorithm to identify and link modes. Where previous papers address deployment of the MAC for comparison of two systems, or tracking over a single dimension, this paper proposes an algorithm suitable for comparisons over an N-dimensional parameter space of the operating condition. The algorithm is deployed using an 'embarrassingly parallel' approach to span modes. Although this enables multiple cores to be used to reduce the time to solution, it is also shown that the computational resources are not being exploited to their full potential, resulting in significant processor idle time. This is applied to a flight dynamics example, for a model of a novel Unmanned Aerial Vehicle (UAV) platform, simulated using a standard 6 Degrees of Freedom (DoF) Equation of Motion (EoM), using the Euler angle description for orientation.

Section 2 provides the motivation behind the proposed framework for the modal identifying and tracking algorithm, and a de-

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