Paper ID: 42523
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Attitude Dynamics (2) (4)

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CLOSED-CHAIN FORWARD DYNAMICS MODELING OF A FOUR-PANEL FOLDING SPACECRAFT STRUCTURE

Abstract

The size and weight constraints of launch vehicles have inspired the development of innovated deployable spacecraft structures technologies. An emerging area in this field takes inspiration from origami folding techniques to stow flat structures with large area relative to the spacecraft bus size, such as solar arrays, star occulters, and antenna. A central challenge for this concept is the deployment dynamics and deployment actuation of the folded structure and spacecraft system. These concepts are often studied through expensive physical testing and prototyping or time costly finite element modeling. Here, we consider modeling the system dynamics using multi-body techniques while using strain energy at the fold hinges to actuate the deployment.

This paper analyzes the dynamic behavior and develops the equations of motion of an origami folded spacecraft structure. The dynamics model is derived using the augmented approach for closed-chain forward dynamics. This is a multi-body approach developed for complex robotic manipulator systems. In this paper, we demonstrate the applicability of this approach to folded deployable spacecraft structures and adapt the approach for general use with spacecraft systems. This approach is desirable due to the computational efficiency of the algorithm that is primarily gained from implementing the recursive articulated body forward dynamics approach.

Origami fold patterns with repeating structure, such as the Miura-Ori and Scheel patterns, are considered. These patterns share the common property of having no more and no less than four panels meeting at each vertex. Therefore, the subsystem case of a four-panel set is analyzed in detail. A generic set of four panels folding at a vertex can be modeled as an undirected multiply connected graph or as a directed acyclic graph with similar qualities to a four bar mechanism. These two modeling options and their consequences are explored and discussed. The closed four-body chain is approached as two two-body arms subject to a system loop constraint and an algorithm to derive the generic equations of motion is developed. Error control methods on the loop constraint are implemented and discussed. The scalability of the algorithm to multiple-loop systems, as would be seen in a repeating origami pattern, is evaluated. Modeling the hinge actuation behavior is studied in detail.