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Higher-order continuation method for the rigid-body kinematic design of compliant mechanisms

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Abstract

Compliant mechanisms are of great interest in precision engineering. In this paper, we propose a higher-order continuation method to help their rigid-body kinematic design. The method helps to investigate the choice of a mechanism configuration through the whole exploration of the workspace, and eases the kinematic analysis to avoid, or take advantage of, the vicinity of kinematic singularities. Such approach is relevant for planar and quasi-planar mechanisms that can be obtained with micro-manufacturing processes adapted to precision applications. The higher-order continuation method allows for a direct and accurate plotting of the input-output relationship of any mechanism by considering only its geometrical closed-loop equations, *i.e.* without the complex derivation of any analytical model. We show that these plots, called bifurcation diagrams, reveal essential information such as the joint velocity profile and the presence of singular configurations. Moreover, the continuous and accurate computation of the mechanism configuration in the vicinity of singularities provides detailed information about the kinematic behavior of the mechanism in its extreme positions. For the design of compliant mechanisms, the designer can advantageously use the bifurcation diagrams to evaluate the relevance of the selected mechanism, then to identify a configuration in order to obtain desired kinematic properties without the derivation of the inverse kinematic model (IKM) or the direct kinematic model (DKM). The method is exemplified with a 3 universal-joint and 3 spherical-joint mechanism (3–US), the IKM and DKM of which cannot be derived analytically. The latter has a large workspace and special kinematic behaviors consisting of a screw-like motion and a platform gyration, which have not been studied before and could lead to novel compliant devices.

Keywords: compliant mechanism, mechanical design, higher-order continuation method, bifurcation diagram, 3–US mechanism, singularity, workspace analysis

1. Introduction

The advantages of compliant mechanisms for precision applications are well known [2], with in particular high resolution capability. Planar and spatial compliant mechanisms are being considered by engineers. 2D geometries are of particular interest as they can be easily produced with micro-manufacturing processes adapted to precision applications. Several works have furthermore shown that planar structures can be used for 3D motions after application of an out-of-plane initial displacement [56, 57] with so-called Laminar Emergent Mechanisms (LEM) [55]. Other works have introduced the use of quasi-planar geometries [5] to benefit from motion amplification [12]. Specific singular configurations of the mechanism are then being used with, for instance, new promising design of medical device [13].

The design of compliant mechanisms can be efficiently performed using the so-called rigid body replacement (RBR) method [1]. The synthesis is then achieved by relying on a rigid-body mechanism, taking into account the properties of compliant joints by spring models. Given their stiffness properties, parallel mechanisms are in this context of particular interest for the development of compliant structures. Several studies are focused on the selection of appropriate parallel architectures for the design of compliant mechanisms [4, 3, 15], which is a difficult design issue

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