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Space Structures II Development and Verification (Orbital deployable and dimensionally stable structures, including mechanical and robotic systems and subsystems) (2)

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DESIGN AND OPTIMIZE OF SOFT ROBOTIC MANIPULATOR BASED ON CABLE-DRIVEN BELLOWS STRUCTURE

Abstract

With the advancement of space technology, space missions have become increasingly intricate. To meet the unique challenges posed by certain unconventional space missions such as the deployment of faulty solar panels, slit laser welding and cutting operations, the soft robotic manipulators with multiple degrees of freedom have become a new research hotspot. This paper has proposed a soft robotic manipulator, which is driven by cable to simplify the air pump driving devices and adopted the bellows structure with high stiffness and continuous deformation to enhance the load capacity of the robot arm and reduce vibration.

The soft robotic manipulator comprises three corrugated bellows structural units arranged in series. The main body of each structural unit is cylindrical corrugated bellows structure divided into three radial sections. The outermost layer of each section is equipped with cables that drive the manipulator's expansion and bending in three directions. The raised structure of bellows is reinforced by disks, maintaining the manipulator's cross-sectional stability. Nylon 11 was chosen as the material for the bellows structure due to its high bending strength (68 MPa), bending modulus (1685 MPa), and high elongation at break (52%). Upon analyzing the task requirements of the soft manipulator, compliance, load capacity, and vibration mode frequency were identified as key evaluation indices for the structural units. Furthermore, it was identified that the wall thickness, corrugated curvature, and tubular curvature of the bellows structure are critical design parameters influencing the manipulator's capacity. The range of key design parameters was determined according to mass and volume constraints. And finite element analysis was conducted across various parameters to acquire a performance evaluation index dataset. Subsequently, multi-Layer Perceptron was utilized to process the data, and the multi-objective particle swarm optimization algorithm (MOPSO) was employed to determine the optimal design parameters.

Comprehensive simulation analyses of the soft robotic manipulator with the optimized parameters, were conducted using Abaqus CAE. Additionally, a series of experiments were performed to assess the evaluation indices, whose relative errors with the simulation results were within 5%. Compared with OctArm and other manipulators, the developed soft robotic manipulator demonstrates exceptional performance, offering a valuable reference for the design of space robotic arms.