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Design, Fabrication and Analysis of Molded and Direct 3D-Printed Soft Pneumatic Actuators

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Abstract : Soft Robotics is a rapidly growing multidisciplinary field where robots are fabricated using highly deformable materials motivated by bioinspired designs. The high dexterity and adaptability to the external environments during contact make soft robots ideal for applications such as gripping delicate objects, locomotion, and biomedical devices. The actuation system of soft robots mainly includes fluidic, tendon-driven, and smart material actuation. Among them, Soft Pneumatic Actuator, also known as SPA, remains the most popular choice due to its flexibility, safety, easy implementation, and cost-effectiveness. However, at present, most of the fabrication of SPA is still based on traditional molding and casting techniques where the mold is 3d printed into which silicone rubber is cast and consolidated. This conventional method is time-consuming and involves intensive manual labour with the limitation of repeatability and accuracy in design. Recent advancements in direct 3d printing of different soft materials can significantly reduce the repetitive manual task with an ability to fabricate complex geometries and multicomponent designs in a single manufacturing step. The aim of this research work is to design and analyse the Soft Pneumatic Actuator (SPA) utilizing both conventional casting and modern direct 3d printing technologies. The mold of the SPA for traditional casting is 3d printed using fused deposition modeling (FDM) with the polylactic acid (PLA) thermoplastic wire. Hyperelastic soft materials such as Ecoflex-0030/0050 are cast into the mold and consolidated using a lab oven. The bending behaviour is observed experimentally with different pressures of air compressor to ensure uniform bending without any failure. For direct 3D-printing of SPA fused deposition modeling (FDM) with thermoplastic polyurethane (TPU) and stereolithography (SLA) with an elastic resin are used. The actuator is modeled using the finite element method (FEM) to analyse the nonlinear bending behaviour, stress concentration and strain distribution of different hyperelastic materials after pressurization. FEM analysis is carried out using Ansys Workbench software with a Yeon-2nd order hyperelastic material model. FEM includes long-shape deformation, contact between surfaces, and gravity influences. For mesh generation, quadratic tetrahedron, hybrid, and constant pressure mesh are used. SPA is connected to a baseplate that is in connection with the air compressor. A fixed boundary is applied on the baseplate, and static pressure is applied orthogonally to all surfaces of the internal chambers and channels with a closed continuum model. The simulated results from FEM are compared with the experimental results. The experiments are performed in a laboratory set-up where the developed SPA is connected to a compressed air source with a pressure gauge. A comparison study based on performance analysis is done between FDM and SLA printed SPA with the molded counterparts. Furthermore, the molded and 3d printed SPA has been used to develop a three-finger soft pneumatic gripper and has been tested for handling delicate objects.

Keywords : finite element method, fused deposition modeling, hyperelastic, soft pneumatic actuator
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