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4D Printing Intelligent Soft Robot with Untethered Motion Ability and Tactile Perception

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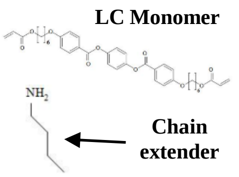
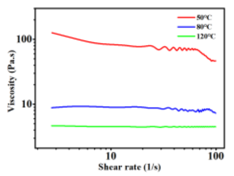
Introduction

4D printing can process smart materials into dynamic architectures with various stimuli responsive behaviours. In addition to simple deformation, it is more attractive to print intelligent soft robot with perception and adaptability. In this work, we developed a single material soft robot with untethered motion ability using 4D printing without any other processing procedures. The printed liquid crystal elastomer soft robot can realize bending deformation, Gaussian curvature deformation, bionic jumping, and untethered rolling when heated. The jumping of the robot is similar to the flea, and it can also realize the hot pressure bounce. The rolling of the robot is stable and powerful while the speed and direction can be adjusted by changing its shape and size. Moreover, the intelligent responsive behaviour of the robot constitutes machine perception based on artificial intelligence. Thus, the proposed robot can be applied in cargo transportation and intelligent exploration of unfamiliar environments in outer space.

LC ink and Physical rheological properties

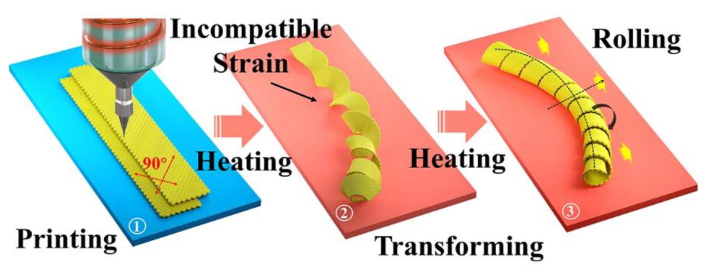




Viscosity of the LC oligomer as a function of shear rate. The LC ink is shear thinning with a wide range of printable viscosities, which provides a relaxed condition for DIW printing.

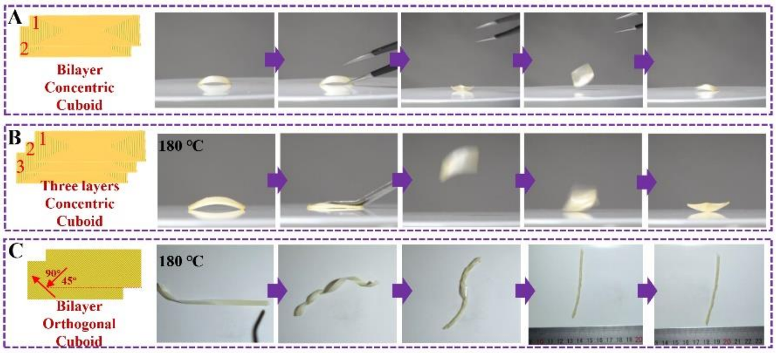
Monomer(RM82)/chain extender(N-butylamine) used in formulating the LC ink.

Printing process, transformation and rolling process



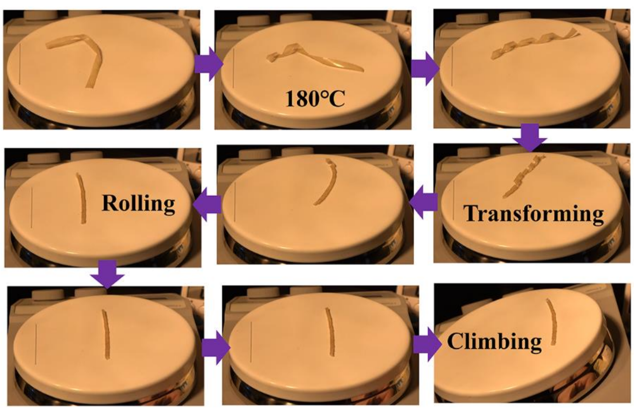
A liquid crystal elastomer-based robot manufactured by 4D printing can realize untethered self-propelled rolling after heated to morph into a tubule. The movement is sustainable toward the curvature direction of the tubule and can be applied to cargo transportation. The robot can surmount or turn back when encountering obstacles of different heights. This behavior can be classified as tactile perception.

At present, the reported 4D printing liquid crystal elastomer mainly realizes the shape change at the fixed position, such as bending, spiral, protrusion, etc. Unless through special later assembly and stimulation setting, it can not realize spatial movement.



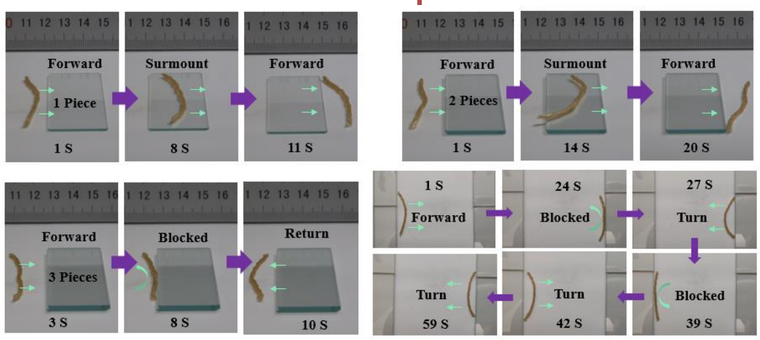
Samples with jumping and rolling motion modes were prepared by printing the liquid crystal monomer macromolecular ink prepared by Michael addition reaction. If the double-layer printed sample is overturned after bulge, it will automatically overturn many times, which is similar to the stress behavior of fleas. The obtained cross printed sample can be turned into a spiral cylinder when heated, and then can be controlled to roll on the heating plate.

Thermal deformation and rolling process of the printed samples



The originally printed 5-mm-wide and 10-cm-long LCE sample placed on the hot plate (180 ° C) curls into a tubule within 20 s and starts rolling automatically. When the heating plate was horizontal, the LCE sample rolled toward the direction of its own curvature at a speed of approximately 48 cm/min. When the right side of the hot plate was lifted, we observed that the LCE sample continued to roll upward along the slope despite the glass tube being dropped. The entire actuating process of the tubular robot is automatic without changing the environmental factors. Additionally, most reported soft robots cannot be isolated from active control owing to their deficient autonomies.

Tactile Perception



Machine perception is an important factor in the field of artificial intelligence. Robots endowed with visual, auditory, tactile, and other perceptual or cognitive abilities can simulate and mimic human behaviors. In the case of a soft robot printed using a single material, the change in geometry is an opportunity to acquire the ability of intelligent perception. As a slight touch can alter the curvature direction to control the rolling direction of the proposed robot, it can automatically respond to external forces when encountering obstacles, similar to an insect with a pair of antennae.

Conclusions

4D printing can process smart materials into dynamic architectures with various stimuli responsive behaviors. In addition to simple deformation, it is more attractive to print intelligent soft robot with perception and adaptability. Obtaining intelligent soft robot directly through 4D printing is still a great challenge. In this work, we developed a single material soft robot with untethered motion ability using 4D printing without any other processing procedures. The rolling of the robot is stable and powerful while the speed and direction can be adjusted by changing its shape and size. Moreover, the intelligent responsive behavior of the robot constitutes machine perception based on artificial intelligence. Thus, the proposed robot can be applied in cargo transportation and intelligent exploration of unfamiliar environments in outer space.

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