4D printing of magneto-actuated devices with tunable mechanical and magnetic properties

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In its early stage, 3D printing was mainly conceived as an innovative manufacturing method to produce objects with complex designs. More recently, the necessity to produce innovative materials with controlled properties by 3D printing technology emerged as a new research topic, which is predicted to boost developments in several application fields such as robotics, sensing, and biomedicine. In the 4D printing framework, 3D printed objects can modify their shape and properties by the applications of external stimuli. In particular, magnetic fields, are easy to apply, they are body-harmless, and they allow to remotely control the motion of the designed objects.

In this presentation, Digital Light Processing (DLP) was used to 3D print magneto-responsive polymeric materials containing dispersed Fe_3O_4 NPs. The magnetic properties of the materials were tailored by controlling the concentration of magnetic filler. Furthermore, playing on the formulation ingredients, the mechanical response of the materials was tuned from stiff to soft enabling different magneto-induced motion such as translation, rolling, bending, and folding/unfolding.

Afterwards, we took advantage of the self-assembly processes of the magnetic particles to fabricate composite materials with programmed microstructures using a modified DLP 3D printer. First, the self-assembly of magnetic particles in chain-like structures was induced by the application of a magnetic field on a thin liquid layer of photocurable resin mimicking the 3D printing process. Once the magnetic chains were formed, their direction was controlled by rotating the applied field of discrete angles.

Finally, the magnetic properties of the materials were tailored by the control of their microstructure. The magnetic anisotropy and the easy magnetic-axis of the composites were tailored by controlling the magnetic field intensity and direction, and by varying the Fe_3O_4 NPs concentration. Throughout the magnetic programming of the microstructure, several devices were fabricated proving remotely controlled rotation and bending motions induced by the application of magnetic torques.

The research findings demonstrated an accessible route to 3D print magneto-responsive polymers with controlled microstructures and magnetic properties. The programming of the nanocomposite microstructure proved to enhance the control of the actuation mechanism and to widen the palette of the exploitable motion typologies.