4D Printing

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Introduction

4D print concept may be strange for today's public. In fact, the idea of 4D printing technology was proposed four years ago. At the TED 2013 conference in California, the MIT showed 4D printing technology to the world and demonstrated it through a complete experiment. 4D printing technology is not only a revolution of the production tool, but also a technology that changes the way in which the business ecosystem works in the future.

Concept

4D printing uses the same techniques as 3D printing to create a three-dimensional object. However, 4D printing adds the dimension of transformation over time. Because the material that 4D printing technology uses is programmable, the three- dimensional object it creates can change its shape over the time due to some parameters in the environment (humidity, temperature, etc.).

How 4D printing works

1. Intelligent material

The most essential part of 4D printing technology must be its printing material, because it is the programmable material that adds the dimension of transformation over time to the 4D printing. In the following, I will be introducing some intelligent materials and will also be talking about the progress have been made on the specific material until now.

1.1electroactive polymer(EAP)

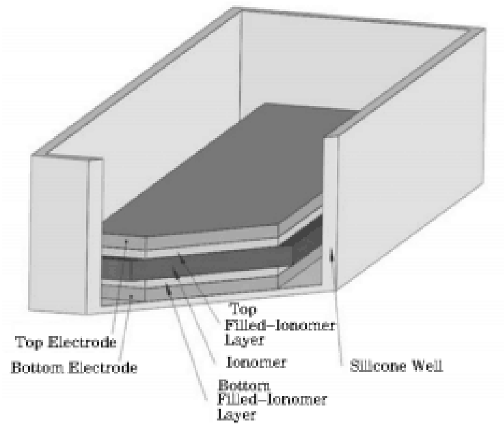
Electroactive polymer material (EAP) is a kind of new flexible functional material which can change its size or shape massively under electric field. EAP is an important branch of intelligent materials, ionized polymer-metal composites (IPMC), Bucky Gel and Dielectric elastomers (DE) are typical examples of EAP.

1.1.1 ionized polymer-metal composites (IPMC)

The IPMC material is a composite material formed by the preparation of electrodes on both surfaces of the ion exchange membrane substrate. Under the external voltage, the ions and water molecules inside the material gather toward the electrode side, resulting an imbalance of mass and charge distribution, and finally causing a bending process.

Evan Malone and Hod Lipson in 2006 for the first time proposed manufacturing three-layer structure and five-layer structure of IPMC intelligent materials with 3D printing technology. The research group used Nafion solution and the mixture of alcohol and water as the precursor material for printing the matrix of IPMC, and they used the mixture of Ag micro particles and Nafion solution as electrode material of IPMC. A cubic silica gel container was 3D printed to support the following process of printing IPMC, just to make sure the liquid printed out does not flow away before curing. In order to reduce the volatilization of the solution and prolong the service life of the IPMC intelligent materials, the Malone task group improved on the basis of the 3D printing 3-layer structure IPMC, and printed a layer of material formed by Hydrin C thermoplastic (Zeon

Chemicals. P.) on the outside of the cured electrode. When the outer layer is cured, a low-conductivity electrode protection layer that cannot be permeated by water is formed. Five-layer structure IPMC made by 3D printing can store solution in the IPMC, and effectively increase the service life.

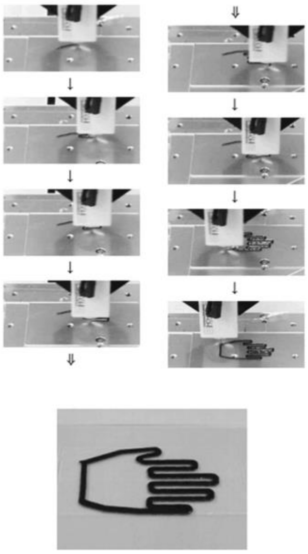


This is a figure which shows the structure of IPMC.

1.1.2 Bucky Gel Actuator/sensor

Bucky Gel consists of a three-layer structure. The intermediate material is composed of polymer and ionic liquid electrolyte layer, and the upper and lower materials are composed of the carbon nanotubes, polymers and ionic liquid electrode material. When loading voltage on both sides of the electrode, the cationic ion in the ionic liquid move toward the two electrodes, causing Bucky Gel to bend.

N. Kamamichi in 2008 proposed an idea that using 3D printing technology to create Bucky Gel. By using 3D printing technology, you can print any complex shape of Bucky Gel that could not been made by traditional method before.



A 3D printed hand with Bucky Gel.

1.1.3Dielectric elastomers (DE

An elastomeric film is coated on both sides with electrodes. The electrodes are connected to a circuit. By applying a voltage the electrostatic pressure acts. Due to the mechanical compression the elastomer film contracts in the thickness direction and expands in the film plane directions. The elastomer film moves back to its original position when it is short-circuited.

R. Shepherd and S. Robinson in 2013 proposed the use of UV-curable silica gel to produce DE material. The substrate material should be UV-curable silica gel material, and the electrode material should be water Gel mixed with carbon black and other conductive particles. By changing the viscosity of silica gel, the printability of silica gel enhances, and by using layer by layer curing technique, three-dimensional structure DE material can finally be printed. The DE material prepared by this method is less deformable, but this method makes it possible to make the complex DE intelligent material structure.

1.2 shape memory materials

Shape memory materials include shape memory alloy (Shape Memory Alloy, SMA), shape memory colloid (Shape Memory Gel, SMG), shape memory polymer (Shape Memory Polymer, SMP) and so on. Shape memory material is characterized by a shape memory effect, the shape of shape memory materials will be fixed at high temperatures, when at low temperature or room temperature, it will cause a plastic deformation, and when the surrounding temperature rose back up to the critical temperature, the deformation disappears and return to its original state. (In short, shape memory material is able to change its shape for several times.) This phenomenon of recovery after heating is called the shape memory effect. Here are the formulas that explain the shape memory effect.

Strain recovery rate (R_r):

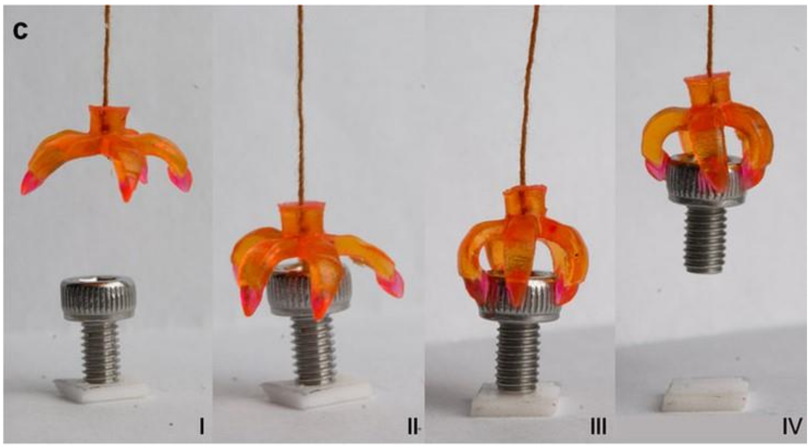
$$R_r(N) = \frac{\varepsilon_m - \varepsilon_p(N)}{\varepsilon_m - \varepsilon_p(N-1)}$$

Strain fixity rate (R_f):

$$R_f(N) = \frac{\varepsilon_p(N)}{\varepsilon_m}$$

"The strain recovery rate describes the ability of the material to memorize its permanent shape, while the strain fixity rate describes the ability of switching segments to fix the mechanical deformation.

Where N is the cycle number, ε_m is the maximum strain imposed on the material, and ε_p (N) and ε_p (N-1) are the strains of the sample in two successive cycles in the stress-free state before yield stress is applied."[1]



A time lapse of an SMP gripper that Qi Ge et al. developed for grabbing and releasing an object.

2. 4D printing techniques

Skylar Tibbits proposed that the core idea of the 4D printing technology is to 3D print intelligent materials with a variety of materials. In this way, the shape of the printed object will change over time because of the intelligent material in it. The group developed a hydrophilic intelligent material which can expanse in the water for about 150%. Hard Organic polymer and hydrophilic intelligent materials are printed at the same time, the composition of two forms an intelligent structure. When the intelligent structure meets the water, the hydrophilic intelligent material expand, and subsequently drive hard organic polymer to bend. When the hard organic polymer encounters the near hard organic polymer barrier, the

[1] **Direct quote from Wikipedia.**

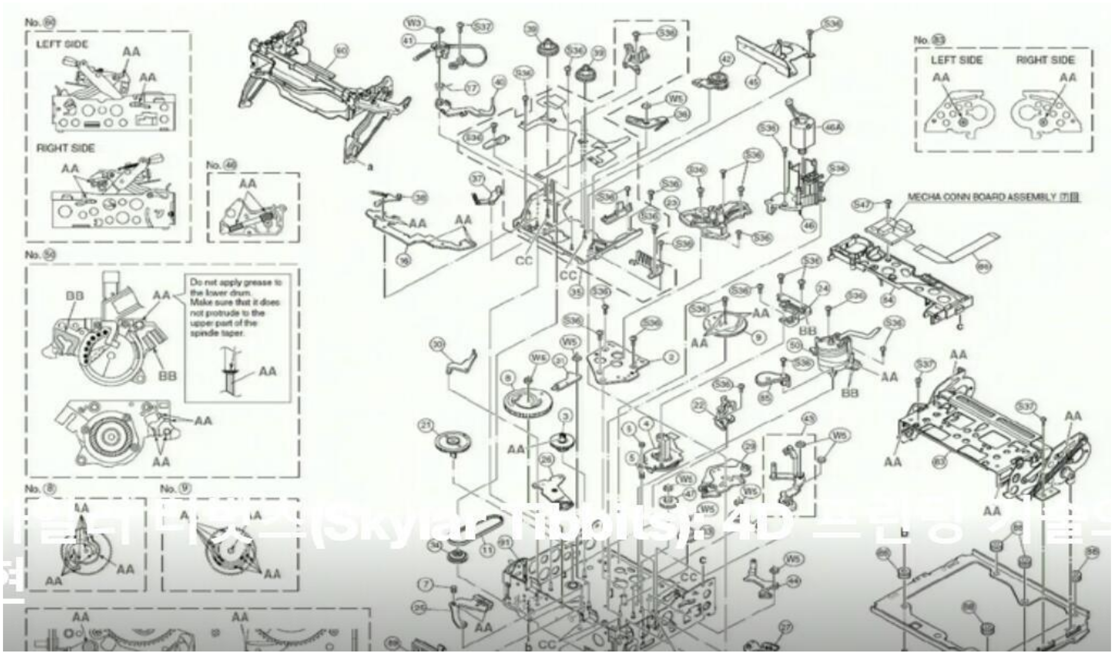
bending deformation ends, thus, the intelligent structure achieves a new state of shape.

These figures show an example of how hydro-reactive polymers react in the water

Why is it so significant?

Traditionally, the process of creation is generally simulating first, and then manufacturing, or, simulating while manufacturing. 4D printing subvert the traditional way of creation.

For example, when we design a machine, we have to make a confusing design



4D printing, however, input the design into the programmable material, and finally, the creation will change to your preferred shape without any external interference. The world of how things are created is going to change if the technology of 4D printing matures.

Applications

4D printing has already been applied to several areas, such as architecture and biomedical. There are also some possible applications such as, military, commerce and transportation, etc.

Conclude

The potential of 4D printing is huge. It will still take a long time to see a 4D printer becoming a daily equipment. When that day actually comes, however, many people might lose their jobs.

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