KTH ROYAL INSTITUTE OF TECHNOLOGY

Closed-Loop 4D Printing with High Precision

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What is 4D Printing?

4D printing is a technology that uses computer-programmed deposition of material in successive layers to create a three-dimensional object that can perform programmed functions, transform their forms or other qualities. More broadly, 4D-printed robots are stimuli-responsive 3D structures, regardless whether their pre-transformation state was 2D- or 3D-printed.

What are the advantages?

The advantage of 4D printing over normal 3D printing is to fabricate products with freeform surfaces made by shin sheets. These products are problematic for 3D printing because there is not sufficient support between adjacent layers. Adding support structures in 3D printing wastes material and requires more time in printing and post processing. Moreover, the geometry of the product may transform between the 2D pattern and the 3D freeform surface repeatedly under proper stimuli. It hence can take the suitable shape in different environments. For example, in medical applications, a surgical tool may be a string outside human body and transformed to the desired shape under higher temperature after entering the human body. The wound in human body is minimised

What are the drawbacks?

Current 4D printing technologies have no closed-loop feedback monitoring and control of the shape changing process. The desired deformation dimensions and bending angles of the active changing structures are designed in advance assuming precise knowledge and no disturbances on the shape changing process. The assumption is certainly not justified because disturbances and modelling errors are unavoidable. The open loop 4D printing process without active control cannot ensure adequate precision. The novelty of this project is to increase the precision and reliability of the 4D printing method by closed-loop control theory and integrated mechatronic design method.

What will be our contribution?

Our study on closed-loop 4D printing will be concentrated on two portions. 1) Closed-loop feedback control of arbitrary shape morphing of 4D printed shape memory polymer (SMP). 2) Closed-loop control of shape morphing and shifting of 4D printed magnetic objects.

Closed-loop control of 4D printed SMP triggered by temperature. SMP is a large group of smart materials that can perform actions due to external stimuli. It is also a widely used material for 4D printing. 4D printed SMP usually has two stable shape states: Permanent shape and temporary shape. Objects are printed as the permanent shape as shown in Figure 1. When heated up above the glass transition temperature, the parts structure is softened and can be twisted into any temporary shape. When cooled down with the temporary shape, this shape will be maintained until the part is placed in high temperature again when the internal stress is able to bring back the permanent shape.

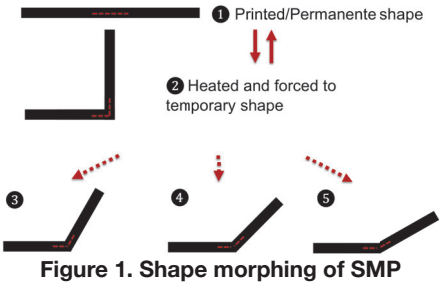

Figure 1. Shape morphing of SMP

The latest advancements still focus on adding multiple stable shapes through structure design or adding more smart materials, which is complex to prepare and the possible shape are inherently limited. Instead, we proposed the implementation of a closed-loop control in a 4D printed SMP integrated with heating units during printing. The SMP can be controlled to maintain multiple temporary states with controlling the heating unit. Only the temporary shape needs to be programmed manually. Arbitrary middle states can be settled in the process. The deformation can be continued after the heating is loaded again. A direct contactless angle monitor is equipped in the system to broaden further applications of this method. Figure 2 demonstrates a successful angle control as a proof-of-concept. The temperature varies according to the system state and angle marches to the target position automatically.

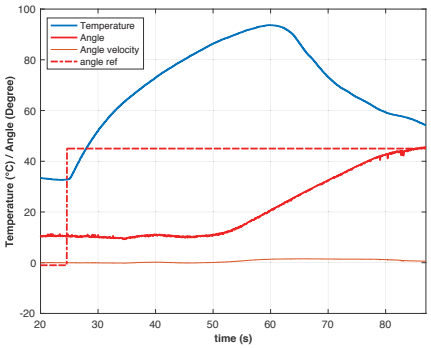

Figure 2. Angle control of 4D printed SMP

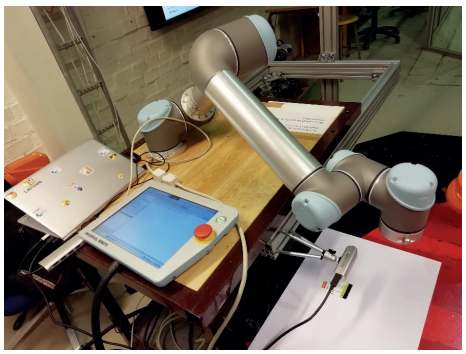

Figure 3. Experimental setup of closed-loop magnetic 4D printing

Closed-loop control of 4D printed magnetic actuation. Magnetic composite material is becoming more and more popular for 4D printing due to its features such as fast response and good programmability. Our work will be focused on the program of magnetic 4D printing and the precise controlled magnetic field triggered actuation.

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