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Design and fabrication of novel discrete actuators for microrobotic tasks

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ABSTRACT

This paper reports a compliant monolithic multistable actuator which is able to switch its moving part between several stable positions linearly in one dimensional direction. The number of stable positions can be increased by extending the range of displacement of the moving part. The transition in each step of displacement is made between two adjacent stable positions. Upward and downward steps are made by a specific sequence of moving, opening and closing two internal clamps which are actuated using three subsystems. The principle and the design of each subsystem followed by the microfabrication process and experimental characterization are reported here. The fabricated prototypes of discrete actuator have shown a proper operation. A successful displacement over 12 upward steps, corresponding to 120.67 ± 0.08 μm distance, has been achieved. The mean displacement step consists of 10.06 μm and closely matches the designed one (10 μm).

1. Introduction

Digital microrobotics is an emergent branch in microrobotics since it offers an alternative to common sensors, by using mechanisms with several stable positions [1–4].

It is quite often that systems composed of bulky sensors and pose some problems such as the noise that increases with respect to the signal for small dimensions, resolution and complicated control laws. The mechanism in digital microrobotics is with discrete actuator that generates several mechanical stable and repeatable positions within the defined range of motion. This property allows to rely on the stable states and to have confidence in the accuracy of targeted positions without sensors requirement while switching from one state to the other. The concept of discrete actuator has many advantages in digital microrobotics, it offers robustness and repeatability of positioning while no measurement systems are required. It is worth to note that removing sensor devices in digital microrobotics helps to simplify the structure, the connectivity and the control. Moreover integrating microrobots in such complicated environments allows to further miniaturizing the systems. As described in the literature, most of the discrete actuators are based on a bistable mechanism [5–17]. Switching between two states, this mechanism guarantees a mechanical stability of the states in open loop without energy consumption unlike stick-slip [18–21], inertial [22–24] or inchworms actuators [25,26]. This widespread mechanism has been employed to design actuators with several stable positions. Among these mechanisms, we find tristable [27–31], quadristable [32,33] and pentastable designs. On the other hand, few unlimited multistable mechanisms are presented in the literature. Gerson et al. [34] presented a multistable microactuator with a large displacement by combining curved beams and serially connected bistable elements. Following, Chalvet et al. reported the concept of a digital microrobot based on parallel distribution of bistable elements [3]. However, those mechanisms are subjected to a trade-off between the stable positions (directly related to the number of bistables) and the dimensions of the mechanism. Due to the combination of bistables, the size of the mechanism increases rapidly. As a consequence, the miniaturization and the control of the mechanism become complex and non-intuitive.

To tackle this limitation, a novel compact discrete actuator is presented in this paper. Instead of combining several bistables, we propose here a new mechanism architecture with multi stable positions. This new architecture allows switching linearly its moving part between several stable positions in one dimensional direction. It combines the accuracy and robustness advantages of multi-elementary stable microsystems with the stepping principle which allows the actuator to have more positions by simply extending the range of motion as the case of stepping microactua-

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tors. Compared to the above mentioned mechanisms, the proposed actuator is a promising solution that adds discrete positions to the workspace with a smaller footprint while adding many advantages. The main characteristics of the new actuator are summarized in the following:

- Compact design with more discrete positions.
- A stepping principle mechanism.
- Positioning robustness due to the digital concept and the use of stable structures.
- The number of internal actuators is reduced and the control is simplified.
- The stability margin due to the holding forces at each stable position.
- Increased accuracy due to the use of a mechanism to compensate microfabrication tolerances.
- No energy is needed to hold the moving part at rest.
- Compliant structure which has many advantages such as increased precision and reliability, no friction, reduced wear, avoided backlash, minimized hysteresis and low manufacturing costs.
- Monolithic structure which is an essential requirement to realize microsystems with common microfabrication processes and allows the integration in complicated environments.

The device is fabricated on SOI wafers using a deep reactive ion etching (DRIE) based process. The fabricated prototype showed a proper functioning in the experiments with accurate and repeatable steps. The novel actuator can be used for accurate positioning applications in MEMS. It can be integrated in more complex systems for more advanced tasks and the design can be changed for different number of stable positions and different step dimensions.

The principle of the multistable mechanism in the novel actuator is presented in section II. Design of the internal systems and components are presented in Section 3. The fabrication process is clarified in Section 4 and finally the experimental characterization is presented in Section 5.

2. Principle of the multistable mechanism

The present multistable actuator is designed in such way the moving part is able to switch between several stable positions along a straight line back and forward. This novel actuator consists of three subsystems (see Fig. 1), each subsystem is composed of two U-shaped electrothermal actuators and flexible structures. These subsystems ensure the switching and holding of the moving part at stable positions.

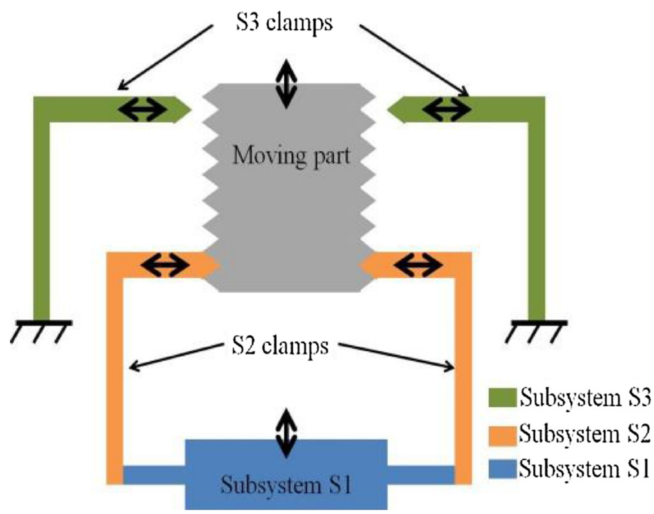

Fig. 1. Illustrative schematic of the multistable actuator.

In the sequel, the three subsystems are respectively referred to S1, S2 and S3 and whereas both clamps of S2 and S3 are referred as S2 clamp and S3 clamp. The subsystem S1 is a bistable module which allows moving up and down S2 clamp. At the rest configuration of S1, S1 and consequently S2 clamp are at the bottom position. The subsystem S2 allows holding the moving part by passive gearing between S2 clamp and the moving part. At the rest configuration of S2, the S2 clamp is closed (see Fig. 1). When S2 is activated, the S2 clamp opens (this action dissociates S2 clamp from the moving part). The combination of S1 and S2 allows to drive upwards and downwards the moving part. The subsystem S3 allows holding the moving part when S2 clamp is opened by an active gearing between the S3 clamp and the moving part (S3 clamp is closed). At the rest configuration of S3, the S3 clamp is opened (see Fig. 1). The displacement of the moving part is guided on a straight line with a couple of curved beams. It is performed by a sequence of moving,

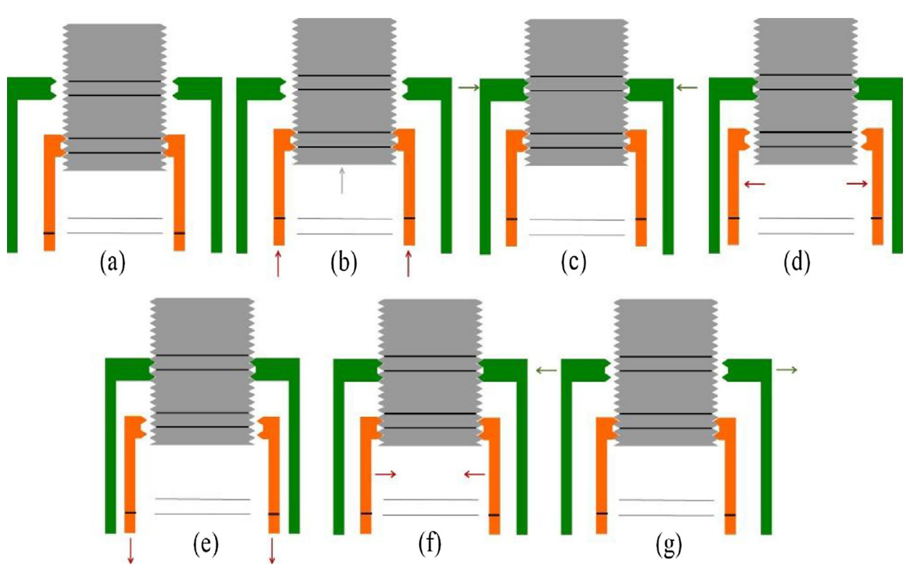

Fig. 2. Sequence order to make an upward step. a) Rest configuration. b) Firstly, S2 clamp moves upwards with holding the moving part, c) S3 clamp holds the moving part, d) S2 clamp releases the moving part, e) S2 clamp moves downwards and f) S2 clamp holds the moving part at bottom position of S1, g) finally, S3 clamp releases the moving part.