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# Stiffness-tunable soft bending actuator based on an antagonistic structure

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***Abstract*—In this study, a soft fabric-based bending actuator with an antagonistic structure is designed and tested. Easy to manufacture and to customise to a wide range of applications, the actuator can modulate its stiffness and bending angle independently, by individually controlling the pressure of internal and external bladders that work antagonistically.**

***Index Terms*—Soft bending actuator, pneumatic actuation, variable stiffness**

## I. Introduction

In the past decade, soft robots have received great attention. Made of inherently flexible materials, their compliance allows them to interact safely and efficiently with their environment, including fragile objects and humans. However, their low-stiffness nature makes them unsuitable for applications where large load capacity or high mechanical stiffness are required. Therefore, it is crucial for soft actuators to be able to adjust their structural stiffness. In this work, we present a soft bending actuator with an antagonistic structure, allowing it to modulate its stiffness and bending angle independently.

## II. Methods

The soft bending actuator consists of a flexible structure, encased within two layers of fabric (Fig. 1A). Each layer forms a chamber whose pressure can be independently controlled from the other. Made of nonstretchable fabric, they work antagonistically: depressurising the inner chamber will lead to a bending motion, while pressurising the outer chamber creates a counter-bending force (Fig. 1B). By simultaneously changing both pressures, a higher pressure difference can be reached, thus increasing the structural stiffness of the actuator, without modifying its current bending angle. TPU-coated nylon fabric is chosen for the chambers' material, as it is robust, airtight and can be heat-sealed to itself at a relatively low temperature, facilitating the manufacturing process. On the other hand, the flexible structure, called the skeleton after [1]'s study, acts like a constraining component, guiding the deformation of the overall system. A string looped around both skeleton's ends attaches it to the fabric layers. As the skeleton is 3D-printed (TPU filament, *Cheetah, NinjaTek*), the actuator's characteristics can be easily customised to a wide range of applications. Here, the chosen dimensions are 20 mm x 9 mm x 50 mm.

To observe the stiffness variations, the force-bending angle profiles are experimentally determined. The actuator is fixed on one end, linked to a dynamometer, while the other end can

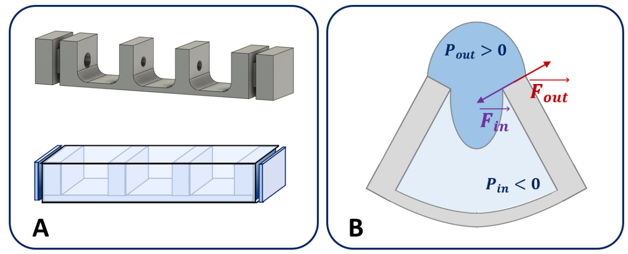


Fig. 1. (A) Skeleton design (top), complete actuator (down). (B) Working principle of the antagonistic structure for a single cell.

be rotated and fixed at regular angular spacings. The deflection is also noted to compute the stiffness. The inner and outer chambers are respectively depressurised at -30 kPa, -50 kPa, and -70 kPa, and pressurised at 20 kPa, 40 kPa, 60 kPa and 80 kPa.

## III. Results

We observe that the slope, image of the actuator stiffness, increases when the pressure difference between the inner and the outer chambers increases. For instance, for a similar maximum bending angle of 26° (when no load is applied), the stiffness for a 70-kPa pressure difference is 1.08 N/mm, while, for a 130-kPa pressure difference, it is 1.76 N/mm, namely a 63% increase. Conversely, identical pressure differences result in similar stiffness but different bending angles, showing the possibility to control independently both characteristics.

## IV. Discussion

In this study, a soft bending actuator, made of two chambers and one internal structure, was able to modulate independently both its bending angle and structural stiffness by individually controlling the pressures inside the chambers. Moreover, the bending aspect of the actuator is controlled by the internal structure, which acts like a constraining component. Therefore, this antagonistic structure could likely be applied to other kinds of motions, by changing this internal structure.

## References

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