Characterisation of Miniaturised Soft Continuum Robots with Reinforced Chambers

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Abstract. The chamber fiber-reinforcement of elastomer-based soft continuum robots can limit a large radial expansion, i.e., the ballooning effect. This radial chamber constraint prevents robots from undergoing unexpected deformations and mitigates interference between actuation chambers. A miniaturised dimension of such robots is of paramount importance for space-constrained applications. As such, we design and experimentally characterise the kinematics and tip force generation for four miniaturised robots, with two diameters (10 mm and 15 mm) and two lengths (46 mm and 66 mm).

Introduction

The ballooning effect of elastomer-based soft robots may result in unexpected deformations and concentrated stresses. To mitigate the ballooning, in-extensible fibre reinforcement has been introduced, originally proposed by Suzumori *et al.* [1]. They designed microactuators with three embeded actuation chambers using fiber-reinforced flexible rubber. Moreover, individual chambers can be reinforced, which can further mitigate the interference between actuation chambers, especially when a working channel exists, e.g., the STIFF-FLOP manipulators (with a diameter of 25 mm) devised for minimally invasive surgery [2], or its miniaturised version (with a diameter of 14.5 mm) [3]. However, an investigation of design parameters of such miniaturised soft robots with individually fibre-reinforced chambers remains to be identified. As such, we experimentally evaluate soft robots using two diameters (10 mm and 15 mm) and two lengths (46 mm and 66 mm).

Results and discussion

The fabricated four robots (denoted by R1-R4) and their geometries are shown in Fig. 1(a). The robot has six circular chambers with two adjacent chambers actuated as one chamber pair. As such, the robot can achieve elongation and omni-directional bending motion. The kinematic results are shown in Figs. 1(b)-(d), with the maximum actuation pressure of 1.5 bar. The maximum average bending angles are 178.4°, 116.1°, 211.7° and 154.7° for R1, R2, R3 and R4 robots, with one chamber pair actuation. By contract, the maximum bending angles increase to 249.1°, 149.6°, 413.3° and 295.7° under two chamber pairs actuation. Fig. 1(d) reports the elongation results with all chambers actuated. R1 and R3 robots show a similar elongation response, with the maximum values of 42.3 mm (for the R1 robot) and 41.5 mm (for the R3 robot). In addition, the maximum elongation is 25.1 mm and 28.9 mm for R2 and R4 robots, respectively. In summary, the bending angle is influenced by both the robot diameter and length. Instead, the elongation is mainly determined by the robot length and less influenced by the diameter. Fig. 1(e) reports the tip blocked force when one chamber pair is actuated. The generated forces show a linear relationship with the pressure, and the maximum force values are 0.35 N, 0.39 N, 0.10 N and 0.12 N for the R1, R2, R3 and R4 robots, respectively. The results show that the generated force is less influenced by the length when the cross-sectional dimensions are the same. It is worth mentioning that the reinforced chamber shapes also have influences on the robots' performances [4].

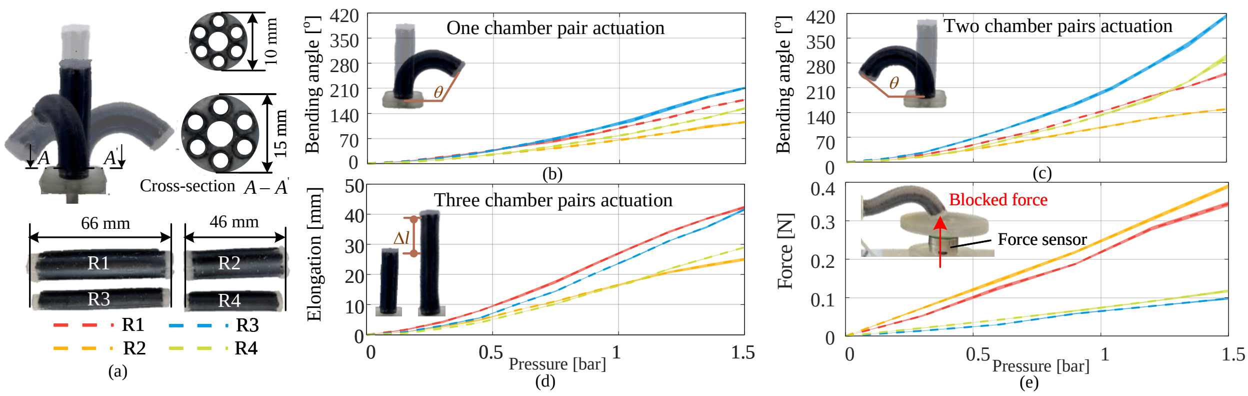

Figure 1: Characterisation results. (a) The designed four robots (R1-R4) and its cross-sectional geometries. The results for (b) one chamber pair actuation (c) two chamber pairs actuation (d) three chamber pairs actuation and (e) tip force generation.

References

[1] Suzumori K. and et al. (1992) Applying a flexible microactuator to robotic mechanisms. *IEEE Control Sys. Mag.*. 12(1):21-27.

[2] Fraś J. and et al. (2015) New STIFF-FLOP module construction idea for improved actuation and sensing. In: *Proc. IEEE Int. Conf. Robot. Autom.* pp. 2901-2906.

[3] Abidi H. and et al. (2018) Highly dexterous 2-module soft robot for intra-organ navigation in minimally invasive surgery. *Int. J. Med. Robot. Comput. Assist. Surg.* 14(1):e1875.

[4] Shi J. and et al. (2022) Design and characterisation of cross-sectional geometries for soft robotic manipulators with fibre-reinforced chambers. In: *Proc. IEEE Int. Conf. Soft Robot,* pp. 125-131.