Improved Fabrication of Soft Robotic Pad for Wearable Assistive Devices

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Abstract. Soft Robotic Pad (SRP), as a new class of soft pneumatic actuator (SPA), is a two-dimensional pad-like SPA that can be programmed to achieve different surface morphing. Recently, the successful fabrication has proven the feasibility of functional SRPs. However, there are issues to be solved so that the SRP can withstand high pressure for practical applications. This paper, based on the first version of the SRP fabrication method, presents some modifications in the method and discusses their pros and cons. Firstly, the incorporation of stiffness customization and patterning method into the SRP fabrication not only simplifies the SRP morphing design, but also makes many morphing modalities possible. Furthermore, the use of larger carbon-fiber rods and the channel filling process improve the SRP strength, which qualifies them to many applications. As an envisioning step, we presents a design of a wearable assistive SRP for elbow flexion. With this fabrication method, the SRP with its unique shape and morphing capabilities has great potential in wearable robotics especially for human joint rehabilitation.

1 Introduction

Silicone based soft pneumatic actuator (SPA), as a signature genre of soft robotics, has been prevailing for a few years [1–5]. Recent developments in fabrication have diversified the SPAs in many ways [4, 6–9]. Despite the diversification, one common feature in the existing SPAs is that they mostly shaped like one straight silicone rod, regardless of their fabrication methods. This one-dimensional design is favored as it is easy to fabricate. However, there are limitations: monotonous motion types due to lack of dimension, and poor force stability because of the low torsion resistance [10].

Recently, two-dimensional flat-shaped SPA in flat shape has emerged in concomitant with certain applications [5, 11–13], however, they are mostly the combination of

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one-dimensional SPAs. The true two-dimensional SPA, termed as soft robotic pad (SRP), was developed in [14] with a novel and well-designed fabrication processes. Only silicone and cotton fiber were used and the fiber were arranged in different formats to constrain the SRP thickness and program the 2D surface morphing. Three types of SRPs were fabricated, bending, saddle and wrapping, to demonstrate the feasibility and the flexibility of the fabrication technique.

However, the key issue is that the SRP sometimes breaks at very low pressure and thus severely affects its application prospects. In this paper, we present some modifications in the fabrication processes and articulate the key benefits and some minor drawbacks. Conclusively, the new fabrication simplifies the SRP motion design, widens the size range up to 40 cm in one dimension and, most importantly, strengthen the SRP by at least 30%. The new fabrication essentially facilitate the utilization of SRP in many applications, especially wearable assistive devices. As a demonstration, we also present a design of a wearable SRP for elbow flexion assist.

2 Improved Fabrication of Soft Robotic Pad

Compared to the previous fabrication method [14], we adopt a method called stiffness customization and patterning (SCP) [9] which is to adhere patterned fabric sheets to the top and bottom surface of the SRP to for motion program. This method not only considerably simplifies the application of the surface constraint, but also makes the motion diversification indeed achievable. In addition, we utilize laser cutting to prepare the patterned fabric sheets.

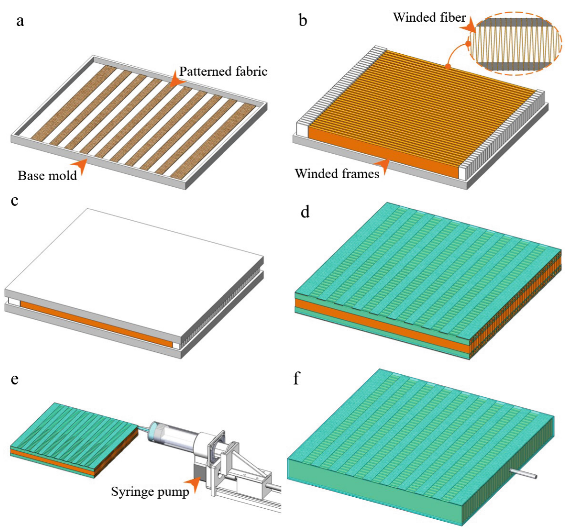

Fig. 1. Improved SRP fabrication. a:mold preparation, b:first layer molding, c:second layer molding, d:halfway SRP after demolding, e:channel filling process, f:final SRP after wall sealing.

As reported in [14], the SRP from the old fabrication suffers from low breaking pressure due to the channel inflation and fiber detachment. To address these issues, our solution is to utilize thicker CF rod (3×3 mm^2) instead of the thin one (Φ1 mm). Using larger CF rod makes the winding frame stronger and supports longer fiber winding (up to 40 cm). During the fabrication, an addition step is needed after the removal of the CF rod which is to fill the channel with fresh silicone. After the curing process, the channels are finally eliminated and the SRP strength can be improved by 30% according to our failure tests. Figure 1 illustrates the new fabrication technique that includes all the modifications.

With the utilization of larger CF rod, the fabrication becomes more tedious because of the time-consuming channel filling process. Another drawback is that the final thickness of the SRPs becomes slightly thicker. However, overall, the benefits of the new fabrication surly outweighs the drawbacks.

3 Design of a Soft Assistive Device for Elbow Flexion

Figure 2 shows the components (top) and final assembly (bottom) of the device. Similar to other SRPs, this elbow-assisting SRP also features a long thin silicone body with a through-all air chamber, vertical fiber matrix for thickness constraint, a non-patterned fabric to constrain the top surface and a patterned fabric to generate the desirable SRP motion as the combination with the top surface constraint. From the bottom fabric pattern, we can see that, at the two ends, the SRP can curl up, which is consciously designed with the purpose of securing the upper arm and forearm during actuation. On the other hand, the major bending in the middle will assist the actual elbow flexion motion. Moreover, the through-all chamber in the SRP can achieve an entire-body stiffening during actuation so that the bending of the SRP can be achieved without collapsing, and the force can be effectively applied onto the upper arm and the forearm. With this SRP, we can achieve multi-motion in one body for a more effective assist.

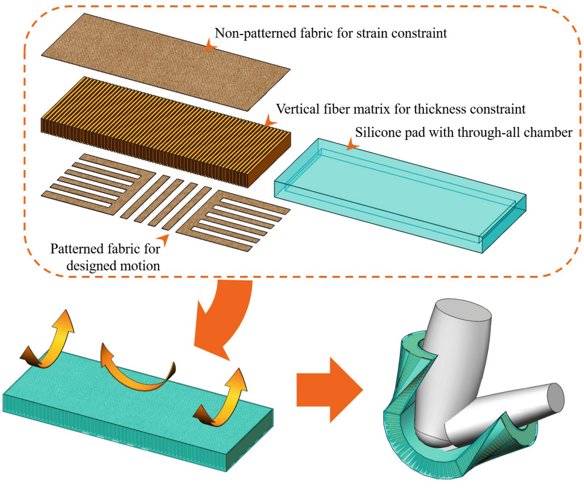

Fig. 2. Design of a wearable assistive SRP for elbow flexion.

4 Conclusion

This paper presents the improved SRP fabrication method with some modifications to the previous fabrication processes: using patterned fabric for surface constraint, using larger CF rods and an additional channel filling process. The pros and cons of the modification has been discussed and, conclusively, the pros outweigh the cons as the modifications simplify the SRP motion programming, support larger SRP size and most importantly enable the SRPs to withstand higher pressure.

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