

Response to Reviewers Comments

We are extremely grateful for your careful and thorough review of this paper. We greatly appreciate all the time you took to help us frame this paper in the context of the field. All the text changes appear as highlighted text in the revised paper.

Reviewer 1:

General Comments:

1. *“Details regarding the geometric parameters for the compared actuators are not provided, making the comparison less meaningful. The paper will benefit if these are clearly stated in the paper.”*

We really appreciate this feedback and completely agree. To address this, we have included the following table in Section 3.2.4, Comparative Characterization:

Table 1: Geometric Parameters of an Actuator Segment

	Actuator Type		
	Ribbed	Cyl.	Pleated
Actuator Length [mm]	37.8	61.2	107.5
Actuator Width [mm]	32.0	33.5	44.4
Actuator Thick. [mm]	18.5	19.6	25.4
# of Channels per Side	13	1	10
Single Channel Length [mm]	25.4	40.0	12.9
Single Channel Width [mm]	3.1	2.8	12.3
Single Channel Thick. [mm]	1.0	2.8	2.8
Cavity Volume per Side [ml]	1.04	0.31	5.12

Furthermore, we added the following description to the text:

“Each segment's geometry and cavity volume is different, because every actuator segment was built with a different type of robot prototype in mind. The geometries and the resulting cavity volumes are listed in Table 1. The different cavity volumes and the characteristic deformations of each morphology under pressurization require significantly different volumetric displacements. Since this is a quasi-static process, fluid pressure and supply volume measurements can be used to determine the elastic potential fluid energy input into the actuation system. The actuation system consists of the elastomeric segment and the internal compressible transmission fluid. The elastic potential fluid energy serves as a comparative metric between the different actuator segment designs.”

Other Comments:

1. *“The organization can be improved. For instance 2.3.1 and 2.3.2 are not fabrication methods.”*

Thank you very much for bringing this to our attention. This was a formatting mistake on our part. We have corrected this by moving Sub-subsections 2.3.1 (Soft Locomotory Robots) and 2.3.2 (Soft Continuum Manipulators) from within Subsection 2.3 (Fabrication) to newly created Subsections 2.4 and 2.5, respectively. Also, for Subsection 2.5 we have included a footnote that indicates this subsection also appears in the author's related work [Andrew D Marchese and Daniela Rus. Design, kinematics, and control of a soft spatial fluidic elastomer manipulator. In International Journal of Robotics Research, 2015. (In revision)].

2. *“Sec. 2.1.3, line 3. It is stated “FEA is a bending actuator”. FEA is not necessarily a bending actuator. There can be extension, twisting and other complex motions. Please reword.”*

This is a very good point, thank you for catching this statement. We’ve adjusted the wording as follows: “Although many motion primitives are achievable with a FEA (e.g., extending, contracting, twisting, and bending) in this work we primarily focus on actuators designed for bending.”

3. *“Sec. 3.2.4: Please provide pictures or schematics of experimental setup, especially for tip force measurements.”*

Figure 9 was added to Section 3.2.4 to describe the experimental setup for the bend angle and force measurements. It shows the behavior of each morphology under maximal actuation. Thank you for this suggestion.

4. *“The remarks in Sec. 3.2.4 , seem to ignore the characteristics at lower volumes and fluid energy. Please state clearly the domain in which the statements are valid.”*

Thank you for bringing this to our attention, we have added text to more explicitly reference the regimes where these observations are valid. Specifically we added the following text: “First,

$\frac{\partial p_c}{\partial V_c}$ is similar among the different morphologies for inputs up to approximately 20 mL. In the regime where V_c is above 25 mL, the pleated morphology has the highest $\frac{\partial p_c}{\partial V_c}$, followed by the cylindrical, and then the ribbed. ... Third, the cylindrical morphology requires the most amount of fluid energy to produce a given bend angle and the ribbed and pleated segments require approximately the same amount of fluid energy to generate equivalent bending. This observation holds over the range of inputs generated during these experiments. Last, the pleated segment requires more fluid energy than both the ribbed and cylindrical morphologies to produce a given tip force for inputs greater than 1 J.”

5. *“For a given fluid energy input the bending angle for the cylindrical actuator is the least while the tip force is highest (when $J < 2$). A discussion regarding this may be insightful for designing such actuators.”*

We agree. A discussion on this topic will help the reader; thank you. We have added the following to Section 3.2.4: “For a given fluid energy input, the bending angle of the cylindrical actuator is the least while the blocking force is the highest. In this morphology, a considerable amount of fluid energy is used to radially expand the actuated channel. This energy does not contribute to axial expansion and therefore does not contribute to the bend angle. However, the radial expansion causes a considerable increase in area moment of inertia, which stiffens the actuator and causes it to have a higher blocking force than the other designs.”

6. *“In Sec. 3.2.4, what limits the energy input to the other actuators relative to the pleated actuators?”*

This is a great question. We added the following text to Section 3.2.4 to address it: “Each actuator was inflated to either its maximum before the elastomer plastically deformed or to the highest feasible bend angle. The pleated prototype is larger in scale than the cylindrical and ribbed, therefore it can be driven to higher energy inputs.”

Reviewer 2: *“No major revisions are required, but few revisions are suggested, especially in the part on related works.”*

1. *“The works on cable-actuated structures should be treated separately from those using SMA. In this latter field, you should consider the following works, very relevant to your analysis:*
 - *Cianchetti M, Licofonte A, Follador M, Rogai F, Laschi C (2014) “Bioinspired Soft Actuation System using Shape Memory Alloys” Actuators, 3(3), 226-244.*
 - *Koh, J.-s. & Cho, K.-j. Omega-Shaped Inchworm-Inspired Crawling Robot With Large-Index-and-Pitch (LIP) SMA Spring Actuators Mechatronics, IEEE/ASME Transactions on, 2013, 18, 419-429*
 - *Kim, S.; Hawkes, E.; Cho, K.; Joldaz, M.; Foley, J. & Wood, R. Micro artificial muscle fiber using NiTi spring for soft robotics Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on, 2009, 2228-2234*
 - *Umedachi, T.; Vikas, V. & Trimmer, B. Highly deformable 3-D printed soft robot generating inching and crawling locomotions with variable friction legs Intelligent Robots and Systems (IROS), 2013 IEEE/RSJ International Conference on, 2013, 4590-4595”*

Thank you very much for pointing us to these very important and relevant pieces of related work. We have formed two new subsections 2.1.1-Shape Memory Alloy Actuators and 2.1.2-Cable Actuators. We have better articulated the difference and also included the additional references.

2. *“In the section on PAM you should include:*
 - *Caldwell, D. G.; Tsagarakis, N. & Medrano-Cerda, G. A. Bio-mimetic actuators: polymeric Pseudo Muscular Actuators and pneumatic Muscle Actuators for biological emulation Mechatronics, 2000, 10, 499 – 530”*

Again, thank you for bringing this reference to our attention. We have added it to section 2.1.3.

3. *“In the section on FEA it may be interesting:*
 - *Cianchetti M, Ranzani T, Gerboni G, Nanayakkara T, Althoefer K, Dasgupta P, Menciassi A (2014) “Soft robotics technologies to address shortcomings in today’s minimally invasive surgery: the STIFF-FLOP approach” Soft Robotics, 1(2) 122-131.”*

We agree, this is a very interesting and new piece of work and we have included it in Section 2.1.4.

4. *“Also in the FEA section, please reduce and/or better discuss your own works, which are cited with very many references (19).”*

Thank you for bringing this to our attention. We have reduced the number of citations to our work in this section; we found some were double referenced by mistake. Now, there are 9 references to our work in this section.