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An octopi inspired soft arm manipulator actuated by tendon-like string configurations

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***Abstract*— Octopi exhibit impressive manipulation abilities and adaptive intelligent behavior. By interpreting their biological structure and their motion generation strategy, a soft robotic continuum arm manipulator inspired by octopi, is presented in this paper. The proposed arm exploits the combination of soft silicone material offering high rates of flexibility and deformability, with rigid supportive disks mimicking the muscular hydrostats present in biological octopi. The arm is actuated by tendon-like string configurations, driving 5 motions in all 3 body planes: Lateral right and left motion in the sagittal plane, ventral and dorsal motion in the coronal plane and helical torsion motion in the transverse plane. By using the compliant body of the proposed arm mimicking the anatomical morphology of the octopi and the 5 motions generated by it, the arm can grasp, move and lift various objects, without previous sensing, and without the usage of suctions cups, making it a powerful low-complexity tool for object manipulation in complex environments.**

Keywords: Soft robotics, biologically inspired robots, soft robot applications, grasping, object manipulation, octopus-like arm

I. INTRODUCTION

There is an increased interest to research robots with new adaptable abilities, that enable them to perform in complex real case scenarios, such as interventions at post disasters stage [1].

The applications of robotics in such cases remains a challenging task [2-5]. In general, conventional robots used in these situations, are equipped with many Degrees of Freedom (DOFs), thus requiring advanced complex controllers and high computational cost. However, biological organisms such as octopi, are able to perform complex tasks and adaptive intelligent behaviors [6-7], despite having relatively small brains. The neural processing that is required to accomplish a task is lowered by the interaction of their body's morphology and material, with the environment. This phenomenon is called "morphological computation" [8-9] and is the underlying feature, present in natural species that enables the exploitation of their body softness to reduce complexity of motion production.

Soft robotics [10-12] aims to transfer the anatomy and the motion mechanisms of natural species to robots, enabling them to quickly adapt to complex environments and safely cooperating with humans.

Due to the intelligent manipulation abilities exhibited by octopi, and their highly adaptable bodies, octopi have been used as inspirational models in developing soft manipulators [13-14]. In these previously researched papers, the manipulator system can grasp various objects. The system is composed of 3 octopus inspired fingers, made of flexible materials that can bend inward through a pulling string mechanism. However, the actuating strings used for driving motion, are placed extrinsically on the rim of the arm and uncovered, prone to damages caused by external conditions, making the proposed arm morphology unsuitable for applications in rough conditioned environments. Moreover, the manipulator can generate only inward bending (2D dorsal motion), thus being able to manipulate only a limited set of objects in 1 body plane. In addition, the manipulation of objects is achieved by using 3 finger-like arms simultaneously, where each of them needs to be individually actuated.

To our knowledge, [15-16] are the only soft manipulators, up to date, inspired by octopi, that can grasp objects, using a singular arm. However, these grippers are equipped with suction cups to realize the object's manipulation, thus requiring a complex arm fabrication procedure and high complexity rates of control (2 sets of controllers are used: one is responsible for arm's bending, while the other for the actuation of the suction cups). Furthermore, these manipulators reach a reported maximum displacement of the actuating strings of 21.6% compared to its arm length. This percentage of maximum displacement may generate insufficient flexibility and grip for the manipulation of objects, without the usage of suction cups. Moreover, in these earlier works, the octopus inspired manipulators produce a maximum of 3 motions in 2 body planes (Festo Gripper [15] can generate only dorsal motion, while [16] can drive 3 types of motion), thus limiting the objects it can handle and offering low mimicry levels of octopi's behavior.

Herein, we propose a soft manipulator composed of a singular arm, inspired by the octopi's morphology and motion strategy, actuated by tendon-like string configurations that are incorporated inside the arm's core. The soft arm can generate a broader range of motions compared to previous works [15-16]: 5 motions in 3 body planes. The proposed arm is a simplified low-complexity model of soft octopi inspired manipulators, that can achieve higher flexibility rates and increased actuating strings displacement, allowing it to manipulate various objects, without previous sensing nor the usage of suction cups.

II. METHODS

The proposed soft arm has the shape of a partially truncated cone, cut perpendicularly to the base. The arm has an overall length of 410 mm, with a maximal diameter at the base of 40mm and minimal diameter at the tip of 5.5mm. It is based on continuum style manipulators [17-18], where only one actuator is required to generate the bending force at the tip, that is transmitted throughout the arm. Based on this continuum structure and the soft body composition, the proposed arm can bend along its length and smoothly interact with the environment.

2.1 Fabrication

The arm is actuated by 5 tendon-like string configurations, represented by an identifying color, that generate motion when pulled with a vector of force directed from base to tip: green string generates left lateral motion, purple for right lateral, red for helical torsion, yellow for ventral and blue for dorsal motion. The string configurations are passed through the cavities embossed in the 15 rigid D-shaped annulus supportive disks, mimicking the muscular hydrostats [19-20] present in biological octopi. The actuating strings and nodded to the most distal disks located at the tip of the arm and covered with oil sheath to reduce friction. The formed continuum structure (shown in Fig.1), is placed on its negative mold designed in Autodesk Inventor, and silicone Dragon Skin 10 is poured and cured for 6 hours. The retrieval of the core from the mold, marks the completion of the arm's first stage fabrication.

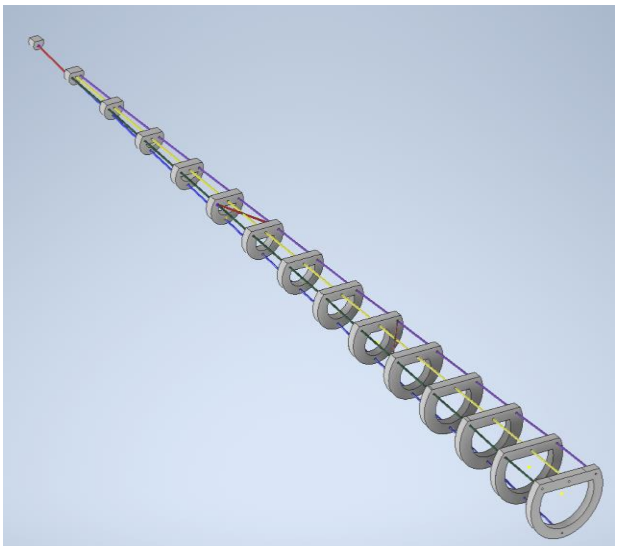

Fig 1. The proposed arm's continuum core structure

The final fabrication stage of the arm is the external covering process. A covering layer with a thickness of 1.5 mm, consisting of Silicone Dragon Skin 10 is poured into the core, to ensure the protection of the actuating string configurations from rupture, and to lower the chances of possible damage occurring to the arm's morphology, during motion.

III. RESULTS

The fabricated soft arm can generate 5 motions in all 3 body planes, by using a pulling mechanism connected to the tendon-like string configurations. The string displacement specifications for each generated motion, are reported in Table 1.

Table 1. Summary of the string displacement data

Motion	Maximal String Displacement (mm)	Maximal String Displacement / Arm's Length Ratio (%)
Left Lateral	210	51
Right Lateral	200	49
Helix	210	51
Ventral	*200*	49
Dorsal	220	54

Torsion or twisting of a muscular hydrostat, results from shortening of helically arranged muscle fibers [19]. Based on this definition, the torsion motion is realized by the co-contraction of the lateral string configurations placed side oppositely to each other, that produce the helical force path along the arm. Fig. 2 illustrates the realized twisting motion.

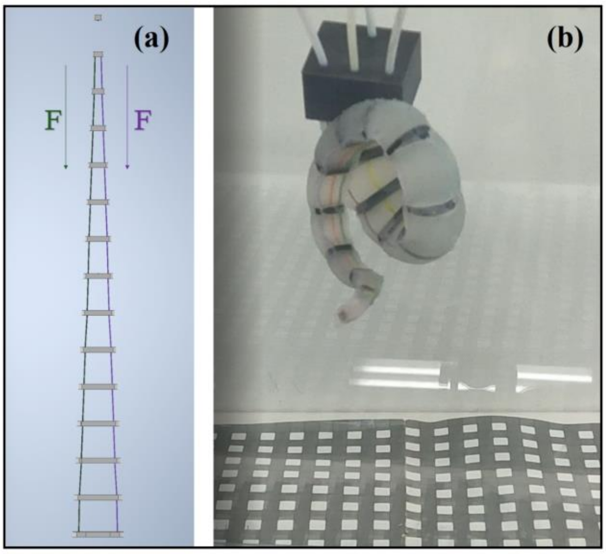

Fig 2. a) The actuating configuration used to drive twisting motion. b) The twisting produced by the co-contraction of the string configuration (a).

To lower the control complexity required for the simultaneous pulling of both lateral string configurations, a single red cable configuration is introduced, which starts as the left lateral strings, and changes paths from left to right and back to left, with a distance interval equal to $1/3^{rds}$ of the arm's length. This described single red cable configuration realizes the helical torsion with a spring like shape.

The left and right lateral motions are realized by pulling respectively the green and the purple string configurations placed side oppositely to each other on the ventral face of the arm.

The dorsal and ventral motions are produced when the blue and yellow string configuration, running centrally on the opposite sides of the arm, are contracted.

3.1 The manipulation of objects using generated motions

The object retrieval is obtained by using the motions generated by the proposed arm: the cylindrical shaped object is manipulated using the right lateral motion, the spherical object using the helical torsion motion, the toroid object through ventral motion and the irregular shaped object by dorsal motion.

The proposed soft manipulator was able to successfully grasp and retrieve the objects of different shapes, surface textures, dimensions, and weights, using the various generated motions. The experimental results of the generated motions and the manipulation of the selected objects, using the proposed soft octopus inspired arm, are shown in Fig.3.

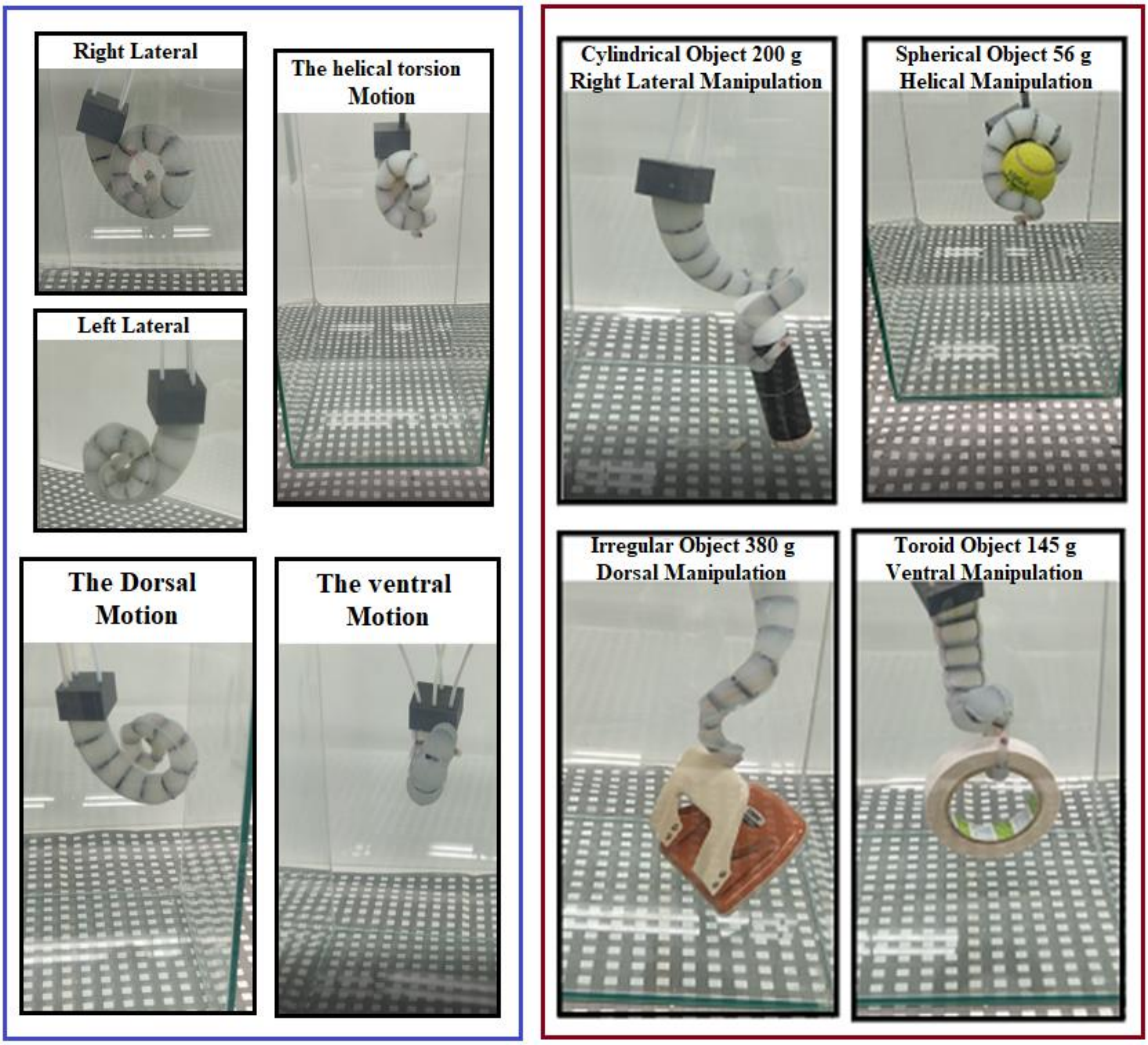

Fig 3. The experimental results of the proposed soft arm manipulator. Left) The 5 motions generated by the arm. Right) The manipulation of objects.

V. CONCLUSION

This thesis paper addressed a soft manipulator, composed of a singular soft arm. The arm is inspired by the morphology of biological octopi, with a curved dorsal face and a flat ventral side. The proposed arm is actuated by tendon-like string configurations, running through rigid disks mimicking the muscular hydrostats that offer support during string's pulling tension, and encapsulated inside soft silicone-rubber material. This arm morphology reduces the risk of actuators breakage from external conditions, making it adaptable for applications in complex rough-conditioned environments.

The contraction of the actuating string configurations generates 5 types of motion in all 3 body planes: left and right lateral motion in the sagittal plane, helical torsion in the transverse plane, dorsal and ventral motion in the coronal plane, compared to previous research where the maximal number of motions achieved was 3, in 2 body planes. The expansion in the types of motions produced by our proposed arm, allow it to achieve higher levels of biological octopi mimicry behavior, and to handle a larger set of objects. The arm achieves a maximal string displacement/ arm's length ratio of 54 %, compared to 21.6% in previous works, making it more flexible and offering tighter grip during object manipulation.

The proposed soft arm manipulator has reduced levels of fabrication and control complexity compared to previous work: a singular arm, without previous sensing and without the usage of suction cups can realize the retrieval of objects consisting of different dimensions, weights, complex shapes and various surface textures. The manipulation is achieved in all anatomical planes: laterally, posteriorly/ anteriorly, and superiorly/ inferiorly, proving generality and versatility of the proposed system.

Future works will apply the proposed soft manipulator in more challenging environmental condition applications. In addition, ANN algorithms are to be included in future decision-making of the manipulators placement and findings of motion non-linearities that are present in soft systems.

REFERENCES

[1] F. Matsuno, Y. Uo, "Current trends in research and development of rescue robot systems," *Journal of the Institute of Electrical Engineering of Japan*, vol.129 pp. 232-236, 2009.

[2] R. Murai, K. Ito, "Snake-like robot for rescue operations: Proposal of a simple mechanism designed for ease of use," *Advanced Robotics,* vol.22, pp. 771-785, 2008.

[3] K. Ito, K. Simodate, "Development of semi-circular duplex manipulator for search and rescue operations in narrow spaces," *International Journal of Advanced Mechatronic Systems, vol.6. No.1, pp.1-11, 2014.*

[4] R.R Murphy, "International Cooperation in Deploying Robots for Disasters: Lessons for the Feature from the Great East Japan Earthquake," *Journal of the Robotics Society Japan,* vol.32, No.2, pp. 104-109, 2014.

[5] R. R. Murphy, "Disaster Robotics," *The MIT Press,* Cambridge, 2014.

[6] G. Fiorito, P. Scotto, "Observational Learning in Octopus vulgaris," Science, vol.256, pp.545-547, 1992.

[7] S.S. Adams, S. Burbeck, "Beyond the Octopus: From General Intelligence Toward a Human-Like Mind. Theoretical Foundations of Artificial General Intelligence," pp.49-65, 2012.

[8] Cangelosi et.al, "Embodied Intelligence," *Springer Handbook of Computational Intelligence*, pp. 697-714, 2015.

[9] R. Pfeifer, F. Lida, "Morphological computation: connecting body, brain and environment," *Proceedings of 19th Australian Joint Conference on Artificial Intelligence,* Australia, 2006.

[10] Laschi et. al, "Soft Robotics: trends, Applications and Challenges," *Springer*, 2016.

[11] Trivedi et.al, "Soft robotics: biological inspiration, state of the art, and future research," *Appl. Bionics Biomech*, vol. 5, pp. 99-117,2008.

[12] Bao et. al, "Soft Robotics: Academic Insight and Perspectives Through Bibliometric Analysis," *Soft Robotics*, vol.5, No. 3, 2018.

[13] K. Ito, Sh. Hagimori, "Flexible manipulator inspired by octopus: development of soft arms using sponge and experiment for grasping various objects," *Artificial Life and Robotics*, vol. 22, No. 3, pp. 283-288, 2017.

[14] K. Ito, K. Mukai, "Flexible Manipulator inspired by octopi: advantages of the pulling mechanism", *Artificial Life and Robotics*, vol. 7, No.1, 2020.

[15] Festo Corporation, Website of Tentacle Gripper by Festo. https://www.festo.com/us/en/e/about-festo/research-and-development/bionic-learning-network/highlights-from-2015-to-2017/tentaclegripper-id_33321/?id_33321/ (accessed: 25 June 2022

[16] Mazzolai et. al, "Octopus-Inspired Soft Arm with Suction Cups for Enhanced Grasping Tasks in Confined Environments", *Adv. Intell. Syst.*, vol.1, 2019.

[17] G. Robinson, J. B. C. Davies, "Continuum Robots- A State of the Art," *IEEE Conf. on Robotics and Automation,* pp.2849-2854, 1999.

[18] M. Hannan, I. Walker, "Kinematics and the Implementation of an Elephant's Trunk Manipulator and other Continuum Style Robots," *Journal of Robotic Systems*, vol.20, No.2, pp. 45-63, 2003

[19] W. Kier, M. Stella, "The arrangement and function of octopus arm musculature and connective tissue," *Journal of Morphology*, vol. 268, pp. 836-838, 2007.

[20] W. Kier, K. Smith "Tongues, tentacles and trunks: the biomechanism of movement in muscular hydrostats," *Zoological Journal of Linnean Society*, vol.83, pp. 307-324, 1985.