Design and Implementation of a Multiple DoF Soft Robot Arm Using Exestensor Muscles

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***Abstract*—This paper proposes a unique soft robot arm. It shows very uncommon behaviour, that a pneumatic platform that can be grasped, contract, extend (stretch), and bend in all directions based on the three designed muscles that connected and operated as parallel actuation. This idea had been launched from an animal whose body has no rigid structures (without bones), like an Octopus, Elephant trunk, and some other animals. The pneumatic muscle actuator (PMA) represents a valuable addition and expansion to the robotics investigation area 20 years ago. These actuators (PMAs) give worthy additions to the robotic systems. These actuators support considerable features like flexibility, lightweight, high force according to weight ratio and the ability to have changeable shapes. This paper has studied a new length model 50 cm to every single extensor PMA. The proposed arm shows about 50% extension ratio and the ability to bend along the three dimensions.**

Keywords—soft actuators, soft robot, pneumatic muscle actuators, continuum arm, animal inspired

I. INTRODUCTION

Since last years, many components have been driven by analysts in both industrial and academic research areas to improve a new Soft Robot Arm. On Other hand, these inventions are based on decreasing or diminishing the cost of the systems and the amount of project materials and increment the amount of products and materials. an end effector can grip as robots are utilised in divisions other than conventional manufacturing [1]

The extensor artificial muscle (PAM) has been used to develop many actuators using the same type of equipment muscle [2].

On other hand, an ordinary mechanical robot arm applies to settle the constrain to the object to maintain a strategic distance from slipping[3], [4]. This can be inefficient in terms of energy utilisation and possible of injury. Similar strategies to those utilised that can be done by a human hand used in robots by connecting. The input from the sensors decreases the involvement unwavering quality on robot operations and makes strides with the end effector workout [5]

The human hand, when it picks up any object, picking up is determined according to the expectations of the object's weight and utilising feedback from the fingertips to avoid the object from slipping by altering the holding force [5], [6].

The cost of the soft robot arm can represent about twenty per cent of the price of the mechanical robot (the whole ROBOT) system, as well as the assignment's requirements and the complexity of the component to be dealt with [7], [8].

In [9], the researchers had been working on contraction muscles to implement soft robot arm, so in our work, we had been working to implement an extensor muscle without any joints with multi degree of freedom DoF by using three identical extensor muscles that connected and synchronised to get any position inside 360 degrees [9],[10].

II. EXTENSOR PENUMATICE MUSCLES ACTUATOR

We had been working to implement an **extensor muscle** robot arm without joints and these extensor muscles can get many DoF (any position inside 360º). Fig.1 shows in detail the structure of the pneumatic muscle actuator.

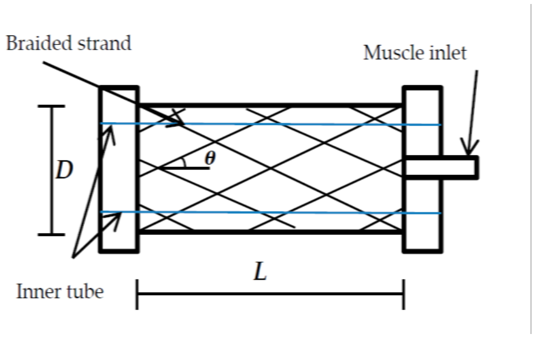

Fig. 1. The structure of the pneumatic muscle actuator.

In the previous 70 years ago approximately, Joseph L. McKibben had been improved the PMA, it made by using a rubber tube wrapped by an expandable sleeve as shown Fig.3 [11].

Artificial PMA actuator structure that displayed it utilise in many applications. Its operational essentials are basic: the bounded pressure of the internal elastic tube is changed over into a vertical pulling force [3][4], [12].

Different air pressure led to various stretch force values and this axial force are affected by PMA extensors showing the general structure of pneumatic muscle actuators.

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$$\varepsilon = \frac{L-L_0}{L} \quad (1)$$

where L is representing the actuator length, D is representing diameter and q represent the braided angle.

In this case, from (1) we have been measured the extinction ratio between the starting muscle length and pressurised length, its value changes between 0 to 0.6 based on the extensor amount and air pressure value, the most perspective within the PMA's activities. The starting amounts are set as L_0, D_0, and θ_0, Consecutively.

The extensor PMAs (pneumatic muscle actuators) represent such as biological muscle [13].[11]. When the diameter of the inner rubber hose becomes smaller as the air pressure rises, it stretches and pulling force is generated. [12], [14], [15].

The guideline operation of the extensor pneumatic muscle can be completely clarified in two situations: (a) variable discuss weight at a settled, joined stack; and (b) changing the stack with steady discuss pressure [3].

The braided sleeve diameter will decrease and the length will be increasing, as a result, the breadth of the PMA increases by increasing the air weight, whereas the actuator length, will increment to reach the maximum extension ratio (ε). Equation (1) gives the extension ratio equation.

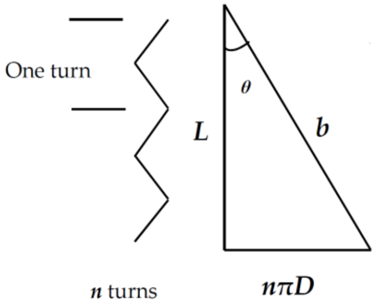

Fig. 2. The parameters of the PMA.

Fig.2 represents the total number of strands turns across the actuator. (Here, n is a constant value for each actuator, which depends on the length and details of the braided sleeve).

Others like L, D, q change based on the level of barometric pressure and the expansion of the muscles of the air. During the test run, the actuator is placed at the top and a specific load is connected to its free end, as shown in Fig.3. Atmospheric pressure gradually rises from zero kilopascals to a constant value. This work shows the similarity between living and pneumatic muscles. The intraoperative extension that begins is called isobaric, and the measurement of the end of the moment of surgery is called isobaric [16].

In the Fig. 2 shows the relationship between PMA parameters. Equations (7), (8), and (9) characterize the representation of the forces of Tongue and Lopez based on the following assumptions. The shape of 1. PMA can be a complete cylinder with zero partition thickness. 2. The inner elastic tube is in contact with the braided sleeve. 3. The length of the three braided strands is constant. 4. There is no grinding between the pipe and the sleeve. 5. Remove restrictions on latex tubes [17].

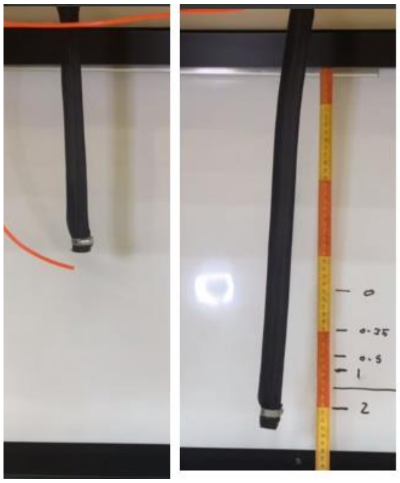

Fig. 3. Expansion of the muscles PMA.

Where from Fig. 2:

$$L = b\cos\theta \quad and \; D = b\,\frac{\sin\theta}{n\pi} \quad (2)$$

Where n is representing the number of strands turns and b is representing length. from equation (2) the strand length can be assessed as:

$$b = \sqrt{(nD\pi)^2 + L^2} \quad (3)$$

Stretch force (f) can be defined as the multiplication of excess pressure and volume over the entire length. [18]

$$f = -\pi r_0^2 p[\alpha(1-\varepsilon')^2 - \beta] \quad (4)$$

Where:

$$\alpha = \frac{3}{\tan^2\theta_0} \; and \qquad \beta = \frac{3}{\sin^2\theta_0}$$

ε' represents the extension ratio for the PMA extensor. furthermore, θ_0 and r_0 denote the starting values of the braided angle and radius of the PMA respectively [19]

Fig. 4. A photograph of a 50 cm PMA.

III. DESGIN THE EXTENSOR SOFT ROBOT ARM

In this paper, we had been working to implement a soft arm robot using extensor PAM instead of contraction to get extra length and more flexibility.

Fig.5a. Soft arm Robot of 3-PMAs before extension

Fig. 5b. Soft arm Robot of 3-PMAs after extension

A 50 cm PMA is utilised to the plan of a soft robot arm, it has been built using four distinguishable PMAs as shown in Fig. 5.

As shown in Fig. 5, there are four muscles are located as a 120^{o} displacement that connected [3], [13], [20], [21]. Furthermore, the distance between the three muscles is equal and the centre muscle (backbone) of the arm is 20mm. so the three muscles have been connected by using an inlet connector that was designed by using 3D printing in Fig. 6.

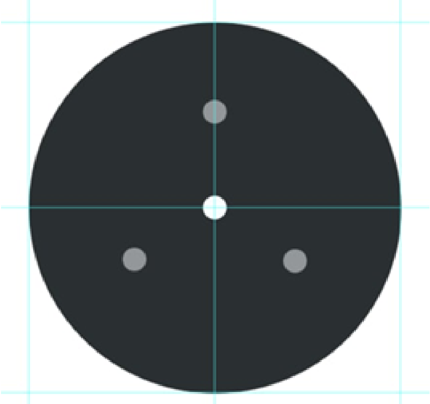

Fig. 6. The upper and lower support for the free end and fixed end.

TABLE I. THE RESULT THAT TESTED ON THE ARM SECTION

Pressure Sensor (Kpa)	Length 1 (cm)	Length 2 (cm)	Length 3 (cm)	Avg Length (cm)
0	50	50	50	50
25	50	50	50	50
50	51	51	51	51
75	56	56	56	56
100	61	61	62	61.333
125	64	64	63	63.667
150	66	66	66	66
175	67	67	67	67
200	68	68	68	68
225	69	69	69	69
250	70	70	70	70
275	70	70	70	70
300	70	70	71	70.333
325	71	71	71	71
350	71	71	71	71
375	71	72	71	71.333
400	72	72	72	72
425	72	72	72	72
450	72	72	72	72
475	72	73	72	72.333
500	73	73	73	73

The same experiments (tests) have been applied to this arm for extension and force characteristics. the result that was tested on the arm section shows us the amount of length based on the pressure that applied through the muscles.

Furthermore, based on the result in Table I we had been got 1.46% from the original length with a good force.

Fig. 7 presented length1, length 2, length 3 and Average length of the extensor PMAs where length 1 is the results from test 1 and length 2 is the results from test 2 and so on.

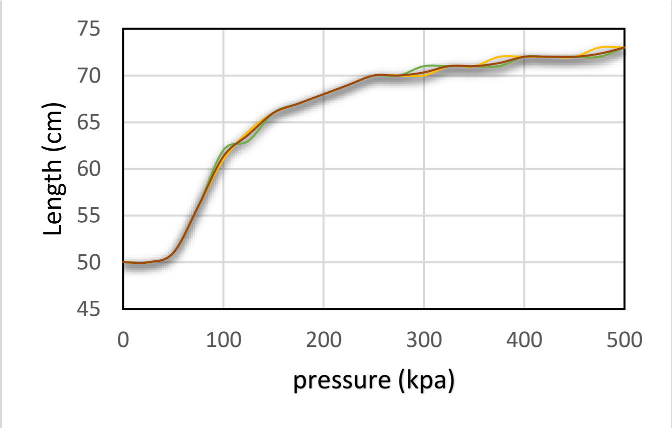

Fig. 7. The length1, 2, 3and Avg of the extensor PMAs.

In Fig. 8 we had been drawing the average length by adding all three lengths and dividing by 3 and all results show in Table I.

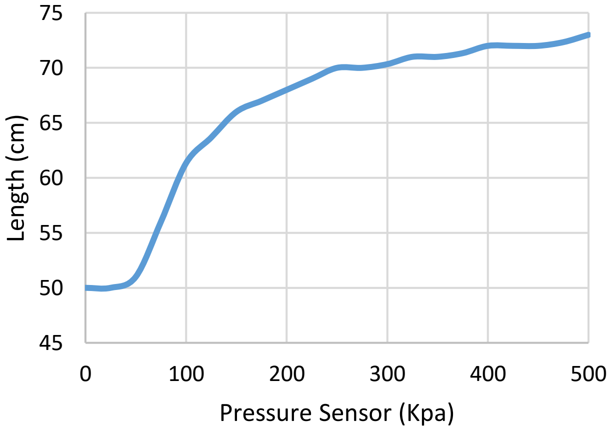

Fig. 8. The average length of the extensor PMAs.

The pneumatic muscle actuator (PMA) arm and macules have The smoothness bending behaviour when it is activated by air [22]. There had been many investigations is done on curvature. In this paper the free endpoint of a 4-PMAs 50 cm arm appeared in Fig.5 is considered and studied as a work of incited air pressure; no-load and stack states are considered. First of all, the experiment and tests have been done by recording the initial and starting angle of the free end (α), that's equal to (zero) degree (0^o) lead to a straight-line Soft robot arm.

Furthermore, all PMAs are incited by (0.25 bar), at that point, the pressure has been increased in one of the PMAs within the corners. The arm has been bending into another position, depending on the amount of pressure (p) in the muscle. On other hand, α is recorded each time. Fig. 9 appear us the extensor arm beneath incitation from a certain pressure between (0-500) Kpa .

In Table II. We have been recorded all the results for Arm bending.

TABLE II. THE RESULT THAT TESTED ON THE ARM BENDING ANGLE

Pressure (Kpa)	Angle α (Degree)
50	23.55
100	69.45
150	88.37
200	92.03
250	93.29
300	104.68
350	114.28
400	119.4
450	122.4
500	132.71

Furthermore, we had to sew the bending amount and fixability in the bending feature through Fig. 9.

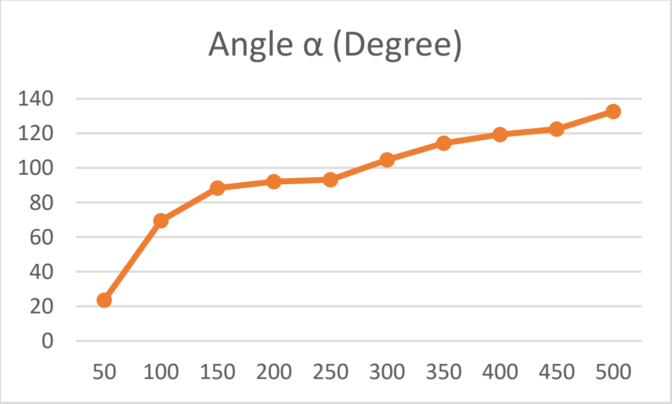

Fig. 9. Angle eof the extensor PMAs.

IV. CONCLUSION

This paper presented many descriptions of the design and implementation of the single extensor PMA. The extensions performance of this actuator is explained for different sizes.

An extensor PMA Robot arm is built from Three extensors PMAs and we studied its behaviour for extension and bending. The experiments show a high bending angle.

The main benefit from this research, we get a good length extra 46% approximately with bend and extending.

As future work, design multi sections arm robot to get flexibility and a control system to be applied on the extensor PMA soft Robot arm.

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REFERENCES

[1] G. Robinson and J. B. C. Davies, "Continuum robots - a state of the art," in *Proceedings 1999 IEEE International Conference on Robotics and Automation (Cat. No.99CH36288C)*, 1999, vol. 4, pp. 2849–2854. doi: 10.1109/ROBOT.1999.774029.

[2] H. Al-Fahaam, S. Nefti-Meziani, T. Theodoridis, and S. Davis, "The Design and Mathematical Model of a Novel Variable Stiffness Extensor-Contractor Pneumatic Artificial Muscle," *Soft Robotics*, vol. 5, no. 5, pp. 576–591, Oct. 2018, doi: 10.1089/soro.2018.0010.

[3] F. Renda, M. Giorelli, M. Calisti, M. Cianchetti, and C. Laschi, "Dynamic model of a multibending soft robot arm driven by cables," *IEEE Transactions on Robotics*, vol. 30, no. 5, pp. 1109–1122, Oct. 2014, doi: 10.1109/TRO.2014.2325992.

[4] C. Laschi, M. Cianchetti, B. Mazzolai, L. Margheri, M. Follador, and P. Dario, "Soft robot arm inspired by the octopus," *Advanced Robotics*, vol. 26, no. 7, pp. 709–727, 2012, doi: 10.1163/156855312X626343.

[5] R. Ranjan, P. K. Upadhyay, A. Kumar, and P. Dhyani, "Theoretical and Experimental Modeling of Air Muscle," vol. 2, no. 4, pp. 112–119, 2012, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.413.4007&rep=rep1&type=pdf

[6] C. Y. Chan, S. H. Chong, S. L. Loh, A. Alias, and H. A. Kasdirin, "Positioning control of an antagonistic pneumatic muscle actuated system using feedforward compensation with cascaded control scheme," *International Journal of Integrated Engineering*, 2020, doi: 10.30880/ijie.2020.12.02.008.

[7] A. Al-Ibadi, S. Nefti-Meziani, S. Davis, and T. Theodoridis, "Novel design and position control strategy of a soft robot arm," *Robotics*, vol. 7, no. 4, Nov. 2018, doi: 10.3390/robotics7040072.

[8] A. Al-Ibadi, S. Nefti-Meziani, and S. Davis, "Design, kinematics and controlling a novel soft robot arm with parallel motion," *Robotics*, vol. 7, no. 2, May 2018, doi: 10.3390/robotics7020019.

[9] C. C. Wong, S. Y. Chien, H. M. Feng, and H. Aoyama, "Motion planning for dual-arm robot based on soft actor-critic," *IEEE Access*, vol. 9, pp. 26871–26885, 2021, doi: 10.1109/ACCESS.2021.3056903.

[10] A. Al-Ibadi, S. Nefti-Meziani, and S. Davis, "A Robot Continuum Arm Inspired by the Human Upper Limb: The Pronation and Supination Rotating Behaviour," 2020. doi: 10.1109/ICECCE49384.2020.9179338.

[11] S. Sareh *et al.*, "Macrobend optical sensing for pose measurement in soft robot arms."

[12] Y. Nishikawa and M. Matsumoto, "A design of fully soft robot actuated by gas–liquid phase change," *Advanced Robotics*, vol. 33, no. 12, pp. 567–575, Jun. 2019, doi: 10.1080/01691864.2019.1626281.

[13] M. Rolf, K. Neumann, J. F. Queißer, R. F. Reinhart, A. Nordmann, and J. J. Steil, "A multi-level control architecture for the bionic handling assistant," *Advanced Robotics*, vol. 29, no. 13, pp. 847–859, Jul. 2015, doi: 10.1080/01691864.2015.1037793.

[14] B. Li, H. Cao, B. Greenspan, and M. A. Lobo, "Development and evaluation of pneumatic actuators for pediatric upper extremity rehabilitation devices," *Journal of the Textile Institute*, 2021, doi: 10.1080/00405000.2021.1929704.

[15] Y. Wang and Q. Xu, "Design and testing of a soft parallel robot based on pneumatic artificial muscles for wrist rehabilitation," *Scientific Reports*, vol. 11, no. 1, Dec. 2021, doi: 10.1038/s41598-020-80411-0.

[16] J. E. Takosoglu, P. A. Laski, S. Blasiak, G. Bracha, and D. Pietrala, "Determining the Static Characteristics of Pneumatic Muscles," *Measurement and Control (United Kingdom)*, vol. 49, no. 2, pp. 62–71, Mar. 2016, doi: 10.1177/0020294016629176.

[17] A. Al-Ibadi, S. Nefti-Meziani, and S. Davis, "Cooperative project by self-bending continuum arms," in *ICAC 2017 - 2017 23rd IEEE International Conference on Automation and Computing: Addressing Global Challenges through Automation and Computing*, Sep. 2017, pp. 1–6. doi: 10.23919/IConAC.2017.8082045.

[18] Z. Gong *et al.*, "An Opposite-Bending-and-Extension Soft Robotic Manipulator for Delicate Grasping in Shallow Water," *Frontiers in Robotics and AI*, vol. 6, Apr. 2019, doi: 10.3389/frobt.2019.00026.

[19] F. Schmitt, O. Piccin, L. Barbé, and B. Bayle, "Soft Robots Manufacturing: A Review," *Frontiers in Robotics and AI*, vol. 5, Jul. 2018, doi: 10.3389/frobt.2018.00084.

[20] W. Mcmahan, B. A. Jones, and I. D. Walker, "Design and Implementation of a Multi-Section Continuum Robot: Air-Octor."

[21] A. Al-Ibadi, S. Nefti-Meziani, and S. Davis, "Design, implementation and modelling of the single and multiple extensor pneumatic muscle actuators," *Systems Science and Control Engineering*, vol. 6, no. 1, pp. 80–89, Jan. 2018, doi: 10.1080/21642583.2018.1451787.

[22] F. Hisch, A. Giusti, and M. Althoff, "Robust Control of Continuum Robots using Interval Arithmetic," in *IFAC-PapersOnLine*, Jul. 2017, vol. 50, no. 1, pp. 5660–5665. doi: 10.1016/j.ifacol.2017.08.1115.