Analysis and Comparison of 3D Printed Soft Pneumatic Actuator Configurations for Swaying Lateral Motion of Planar Objects

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ABSTRACT

Soft pneumatic actuators (SPAs) offer unique possibilities in robotics and automation due to their compliance and versatility. Unlike conventional actuators that can move either revolute or prismatic, SPAs can produce complex motions, especially when configured in combinations. This paper systematically investigated the performance of four distinct SPA configurations (Types 1-4) concerning the task of moving a planar square object and swaying it laterally to the right and left. These configurations are analyzed for their ability to achieve desired movements and orientations. Type 4, involving two SPAs, emerges as the most effective configuration, successfully navigating the challenges posed by the desired task. In contrast, Type 2, consisting of four SPAs, encounters difficulties in executing the task attributed to increased inertia, which was similar as type 3. Types 1, while not precisely meeting the primary task, reveal distinctive movements - left-right motion without orientation change. This study contributes valuable insights into the complex dynamics of SPAs, offering considerations for optimal design and performance. The outcomes could be developed in the future in soft actuator applications, especially those involving configurations based on specific needs.

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I. Introduction

Soft actuators display a flexible characteristic that sets them apart from conventional actuators such as servos and motors. Initially inspired by the flexibility and compliance observed in biological movements, researchers in recent years have sought to create actuators capable of mimicking these motions [1][2][3][4]. With this unique feature, soft actuators hold significant potential for applications that were once impractical or challenging for conventional actuators. Examples include navigating through narrow spaces, engaging in physical interactions with living organisms, and delicately gripping fragile objects [5][6].

Soft actuators are classified based on their modes of movement and the mechanisms driving them, such as the use of cables, smart materials, and pneumatic systems [7]. Among these, the soft pneumatic actuator (SPA) stands out as a simple yet highly effective option for several reasons [7][8][9]. The simplicity of SPA lies in its reliance on a pneumatic system, a readily available component in most workshops and laboratories. Despite its simplicity, SPA exhibits a remarkable ability to generate significant curvature and force for effective manipulation [10][11][12][13].

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Soft actuators can be used individually or in groups to achieve specific movements. Similar to conventional actuators, the coordinated movement of several soft actuators can generate unique kinematics or motions. However, unlike conventional actuators, which typically produce either revolute or prismatic movement, soft actuators could create complex and intricate motions. Therefore, the combination of multiple soft actuators presents an intriguing topic for discussion.

Some research that utilizes single SPA to move things [14][15][16]. Meanwhile, others tried to use multiple actuators to do specific application [17]. However, there is still few research conducted to investigate the movement produced by the combination of 3d printed soft pneumatic actuator that is created in PneuNet shape.

In this research, we explore the combination of multiple soft actuators capable of lifting planar square objects and swaying them laterally to the right and left. The investigation involves a comparison of four configurations of soft pneumatic actuators. The resulting movements will be analysed to determine the most effective configuration.

This research aims to contribute to the advancement of soft actuator applications. The results are expected to facilitate the utilization of soft actuators for moving planar square objects, thereby inspiring further research in this field.

II. Method

The research was conducted using an experimental method. Four steps were undertaken in this research: designing the soft actuator, 3D printing, selecting configurations for comparison, and measuring and analyzing the results.

A. SPA Design

The soft pneumatic actuator (SPA) design employed in this research was the PneuNet shape. This specific type of SPA exhibits a bending movement when inflated by pressurized air, attributed to the distinct elongation between its top and bottom parts. The variation in elasticity results from the differing shapes of these parts [18][19][20].

The design of the soft pneumatic actuator (SPA) plays a crucial role in its performance [11]. Therefore, the SPA design utilized in this research was standardized, as depicted in Fig. 1. Each SPA consists of 7 chambers, with each chamber having a length of 6 mm. The thickness of the SPA was set at 1 mm.

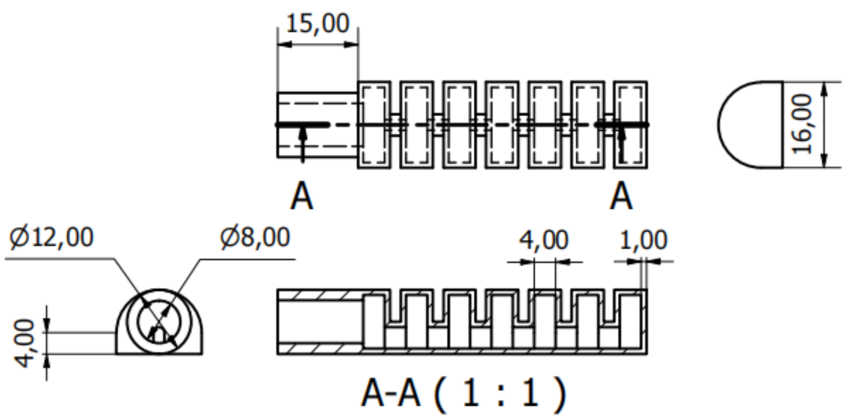

Fig. 1. The design of soft pneumatic actuator.

B. Printing

The soft pneumatic actuators (SPAs) were printed using fused deposition modeling (FDM) 3D Printer, known for its affordability and simplicity yet capable of delivering sufficient performance for printing high-quality soft pneumatic actuators. The material chosen for printing the SPAs was TPU eFlex from the eSUN brand. Precise printing parameters are crucial to ensure the quality of the printed object. The applied printing parameters in this research can be found in Table 1.

Table 1. Printing parameter of SPA.

Printing Parameter	Value
Infill	100%
Infill Pattern	Lines
Print Speed	10 mm/s
Print Temperature	220° C
Build Plate Temperature	78° C
Flow Rate	130%
Layer Thickness	0.1 mm
Fan Speed	0
Support	No Support
Build Plate Adhesion	Skirt

C. SPA configuratios to be compared

1) Type 1

In Type 1, four soft pneumatic actuators (SPAs) were utilized, each connected with a hook that connected to every corner of the planar square object, as illustrated Fig. 2. The design of configuration type 1. Two of the SPAs were oriented towards the right side, while the other two faced in the opposite direction. In Type 3, two SPAs were employed to move the object. The SPAs were positioned in line and back-to-back in the opposite direction. The direction of the SPAs' movement was parallel to the line of their location.

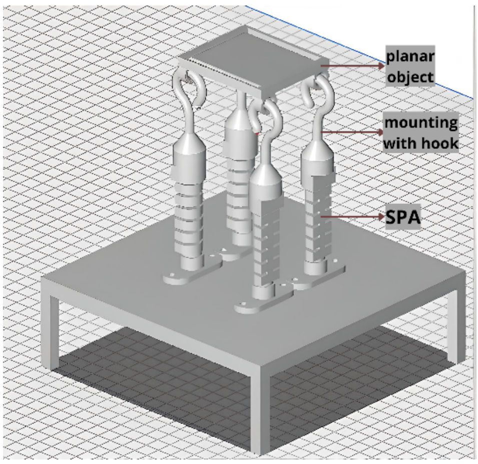

Fig. 2. The design of configuration type 1

2) Type 2

In Type 2, there were four SPAs, similar to Type 1, as depicted in Fig. 3. However, unlike Type 1, there was no hook in Type 2, resulting in the direct transmission of force from the actuator to the planar object. It was anticipated that by eliminating the hook, the transmitted force would be larger.

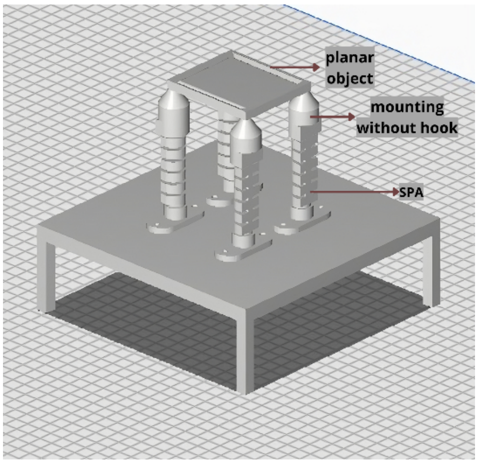

Fig. 3. The design of configuration type 2.

3) Type 3

In Type 3, two SPAs were employed to move the object. The SPAs was positioned in line and back to back in the opposite direction. The direction of the SPAs' movement was parallel to the line of their location. The design, position, and movement direction of the SPAs are illustrated in Fig. 4. In Type 3, two SPAs were employed to move the object. These SPAs were positioned in a line, with one facing to the right side and the other in the opposite direction**. The direction of movement of the SPAs was perpendicular to the line of their location**, distinguishing it from Type 3. It was anticipated that by utilizing this configuration, the energy efficiency could be enhanced by reducing the resistant load caused by two passive SPAs, as designed in Types 1 and 2.

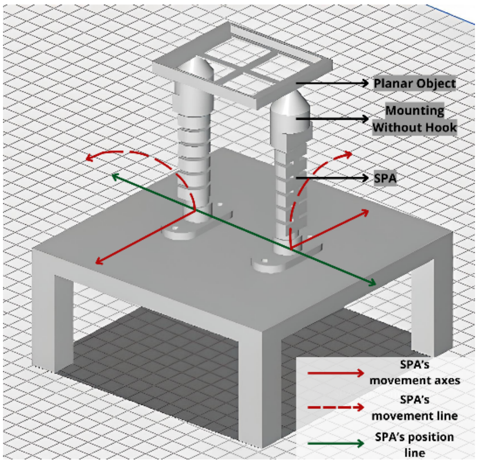

Fig. 4. The design of configuration type 3.

4) Type 4

In Type 4, two SPAs were employed to move the object. These SPAs were positioned in a line, with one facing to the right side and the other in the opposite direction**. The direction of movement of the SPAs was perpendicular to the line of their location**, distinguishing it from Type 3. It was anticipated that by utilizing this configuration, the energy efficiency could be enhanced by reducing the resistant load caused by two passive SPAs, as designed in Types 1 and 2. The design of configuration type 4 can be seen in Fig. 5.

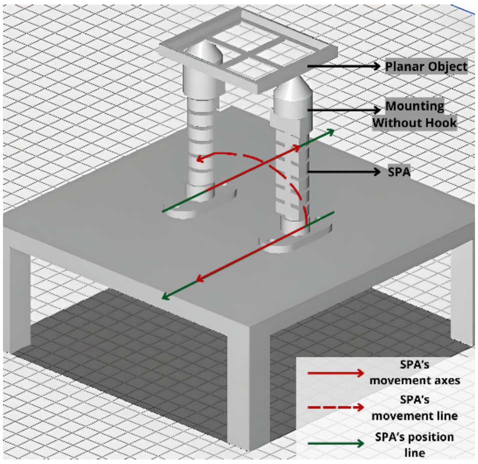

Fig. 5. The design of configuration type 4.

D. Experiment

The experiment involved inflating the SPAs with pressurized air obtained from a Lakoni 8-bar model compressor, which was distributed to each SPA. An air regulator valve, positioned between the SPAs and the compressor, was used to monitor the provided pressure.

Two evaluations were conducted. The first aimed to observe whether each configuration could successfully move the planar object to swaying them laterally the right and left. If two or more configurations succeeded the firs evaluation, the second evaluation measured the pressure required to move the object to a specific position.

III. Result

A. Type 1

In Configuration Type 1, the movement of the soft actuators indeed followed the desired path. However, the orientation of the square planar object remained unchanged and did not align with the orientation of the actuator. While the presence of the hook succeeded in transmitting the force, it failed to transmit the orientation. The movement produced by Type 1 configuration is shown in Fig. 6.

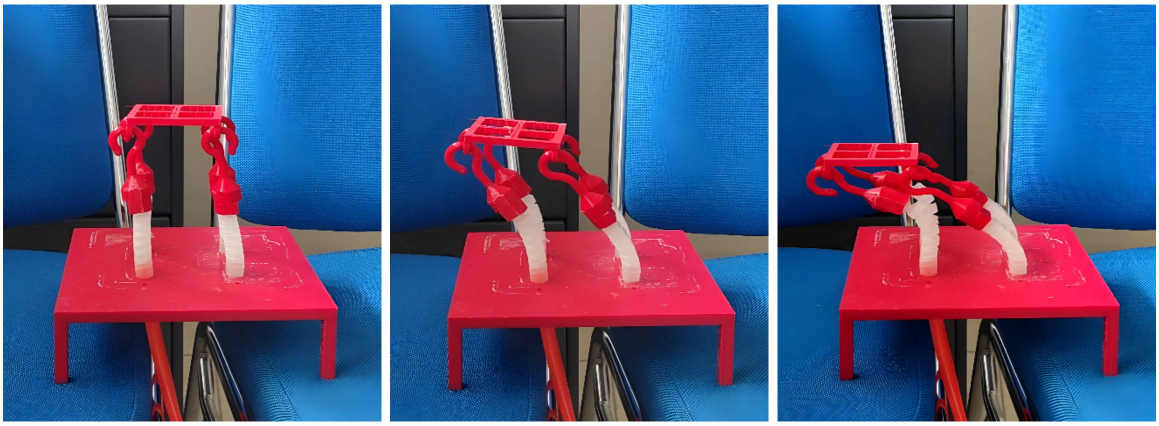
Fig. 6. The movement of configuration type 1 when actuated.

B. Type 2

In Configuration Type 2, the movement of the soft pneumatic actuators did not follow the desired path, as shown in Fig. 7. In fact, the actuators were unable to move the planar square object and extended upright instead of bending. It is likely that the force generated in the two planes could not surpass the inertia of the configuration, resulting in the tendency of the system to maintain a constant position.

Fig. 7. The movement of configuration type 2 when actuated.

C. Type 3

In Configuration Type 3, the soft actuator failed to move the object in the planned direction. Rather than aligning with the face of the SPAs, the object unexpectedly fell behind to the left and right, perpendicular to the intended orientation. This unique behavior suggests that the soft actuator struggled to overcome the inertia of the system. Visual representation is available in Fig. 8.

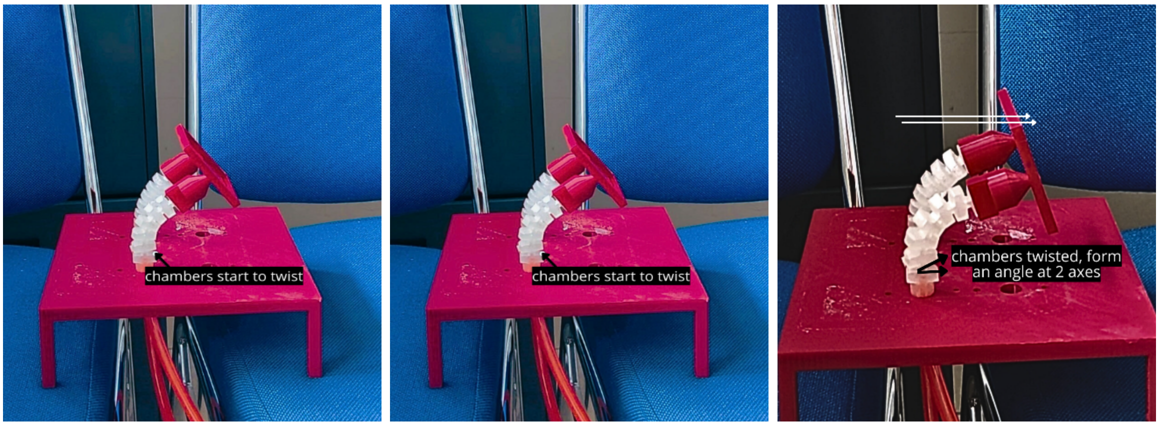

Fig. 8. The movement of configuration type 3 when actuated.

D. Type 4

In Configuration Type 4, the soft actuator successfully positioned and oriented the square planar object, as can be seen in Fig. 9. The non-back-to-back position of the actuator appeared to facilitate smoother handling and movement by the SPAs, meeting expectations.

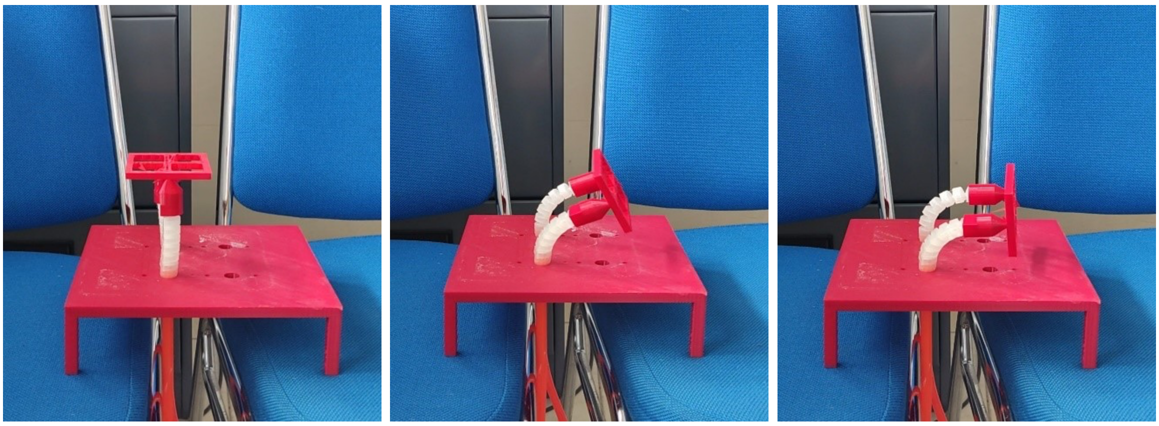

Fig. 9. The movement of configuration type 4 when actuated.

IV. Discussion

Table 2.The summary of the result of each type of SPA configuration.

Type	Move to the right direction	Move to the right orientation
1	v	x
2	x	x
3	x	x
4	v	v

The results of the experiment are summarized in Table 2.The summary of the result of each type of SPA configuration.. It can be seen that Type 4 stands out as the most effective configuration for achieving the intended task of moving the square planar object swaying them laterally to the right and left, which was the primary objective of this experiment. In Type 4, the soft pneumatic actuators successfully moved the square planar object in the desired direction and orientation.

In the opposite side, configuration Type 2 and 3 performed the least effectively, as the soft actuators failed to bend and move the square planar object. It appears that employing back-to-back soft actuators increased inertia, and this challenge could not be overcome by two actuators alone unless an additional component, such as the hook in Type 1, was introduced at the joint to facilitate smoother transmission.

Although configurations Type 1 did not execute the task as intended, they exhibited unique movements that could prove useful in other applications. For example, configuration Type 1 could find utility in applications requiring left and right movement without a change in orientation on the planar object.

V. Conclusion

This study systematically assessed four configurations of soft pneumatic actuators (SPAs) in the context of moving a planar square object swaying to the left and right. The standout performer was found to be configuration Type 4, achieving both the capability to move the object into desired movement and orientation. The most incapable configuration was Type 2 following by type 3 which could not move the object and stayed in its position.

While Types 1 did not precisely meet the primary task, they unveiled unique movements. The Type 1 suit with a left-right motion without orientation change. These outcomes highlight the nuanced considerations in soft actuator design and their potential applicability in diverse scenarios.

The findings of this study contribute valuable insights into the complex dynamics of soft pneumatic actuators. This understanding is crucial for future developments, emphasizing the need for tailored configurations based on specific application requirements.

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References

[1] S. Kim, C. Laschi, and B. Trimmer, “Soft robotics: a bioinspired evolution in robotics,” *Trends Biotechnol*, vol. 31, no. 5, pp. 287–294, May 2013, doi: 10.1016/J.TIBTECH.2013.03.002.

[2] D. Rus and M. T. Tolley, “Design, fabrication and control of soft robots,” *Nature*, vol. 521, no. 7553, pp. 467–475, 2015, doi: 10.1038/nature14543.

[3] N. Tan, X. Gu, and H. Ren, “Design, characterization and applications of a novel soft actuator driven by flexible shafts,” *Mech Mach Theory*, vol. 122, pp. 197–218, 2018, doi: 10.1016/j.mechmachtheory.2017.12.021.

[4] X. Tang *et al.*, “A Review of Soft Actuator Motion: Actuation, Design, Manufacturing and Applications,” *Actuators*, vol. 11, no. 11, p. 331, Nov. 2022, doi: 10.3390/act11110331.

[5] A. D. Marchese, R. Tedrake, and D. Rus, “Dynamics and trajectory optimization for a soft spatial fluidic elastomer manipulator,” *International Journal of Robotics Research*, vol. 35, no. 8, pp. 1000–1019, 2016, doi: 10.1177/0278364915587926.

[6] C. Tawk and G. Alici, “A Review of 3D-Printable Soft Pneumatic Actuators and Sensors: Research Challenges and Opportunities,” *Advanced Intelligent Systems*, vol. 3, no. 6, p. 2000223, 2021, doi: 10.1002/aisy.202000223.

[7] G. M. Whitesides, “Soft Robotics,” *Angewandte Chemie - International Edition*, vol. 57, no. 16, pp. 4258–4273, 2018, doi: 10.1002/anie.201800907.

[8] H. K. Yap, H. Y. Ng, and C. H. Yeow, “High-Force Soft Printable Pneumatics for Soft Robotic Applications,” *Soft Robot*, vol. 3, no. 3, pp. 144–158, 2016, doi: 10.1089/soro.2016.0030.

[9] A. Zolfagharian *et al.*, “actuators : fabrication , modelling , and control and control,” 2020, doi: 10.1080/17452759.2020.1795209.

[10] N. Gariya, P. Kumar, B. Prasad, and T. Singh, “Soft pneumatic actuator with an embedded flexible polymeric piezoelectric membrane for sensing bending deformation,” *Mater Today Commun*, vol. 35, Jun. 2023, doi: 10.1016/j.mtcomm.2023.105910.

[11] Syahirul Alim Ritonga, “Analysis of The Effect of Dimensions, Number of Chambers, and Geometry on Strength and Curvature of 3D Printed Soft Pneumatic Actuator As a Stroke Rehabilitation Glove,” Bachelor Thesis, Universitas Gadjah Mada, Yogyakarta, 2019.

[12] Laschi C, Mazzolai B, and Cianchetti M, “Soft robotics: Technologies and systems pushing the boundaries of robot abilities,” *Sci Robot*, vol. 1, no. 1, Dec. 2016.

[13] M. Paterna, C. De Benedictis, and C. Ferraresi, “The Research on Soft Pneumatic Actuators in Italy: Design Solutions and Applications,” *Actuators*, vol. 11, no. 11. MDPI, Nov. 10, 2022. doi: 10.3390/act11110328.

[14] S. Alim Ritonga, “Comparative Analysis of Custom-Designed Soft Pneumatic Actuators for Human Thumb Movement in Post-Stroke Rehabilitation.” [Online]. Available: http://inotera.poltas.ac.id

[15] J. Paek, I. Cho, and J. Kim, “Microrobotic tentacles with spiral bending capability based on shape-engineered elastomeric microtubes,” *Sci Rep*, vol. 5, Jun. 2015, doi: 10.1038/srep10768.

[16] E. Siéfert, E. Reyssat, J. Bico, and B. Roman, “Bio-inspired pneumatic shape-morphing elastomers,” *Nature Materials*, vol. 18, no. 1. Nature Publishing Group, pp. 24–28, Jan. 01, 2019. doi: 10.1038/s41563-018-0219-x.

[17] J. Shintake, V. Cacucciolo, D. Floreano, and H. Shea, “Soft Robotic Grippers,” *Advanced Materials*, vol. 30, no. 29, 2018, doi: 10.1002/adma.201707035.

[18] M. Manns, Morales, and P. F. Fo, “Additive manufacturing of silicon based PneuNets as soft robotic,” *Procedia CIRP*, vol. 72, pp. 328–333, 2018, doi: 10.1016/j.procir.2018.03.186.

[19] B. Mosadegh *et al.*, "Pneumatic Networks for Soft Robotics that Actuate Rapidly," pp. 2163–2170, 2014, doi: 10.1002/adfm.201303288.

[20] S. Wakimoto, K. Suzumori, and K. Ogura, "Miniature pneumatic curling rubber actuator generating bidirectional motion with one air-supply tube," *Advanced Robotics*, vol. 25, no. 9–10, pp. 1311–1330, 2011, doi: 10.1163/016918611X574731.