Fabric Pneumatic Artificial Muscle with a Gripper

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Abstract

Soft robots provide a lot of advantages over rigid robots in flexibility, power, independence, and mobility. The common examples of soft robots are artificial muscles and universal grippers. However, a soft robot which can implement the functions of both of these robots has not been made. We present an extensive and robust soft robot made of the pneumatic artificial muscle and the universal grippers. The main body of the pneumatic muscle is attached to the universal gripper with zip ties. Thus, it is achievable to behave like a pneumatic muscle and a universal gripper when pressurized. More functions are obtained, such as lifting objects up and moving objects to certain distances. Experiments show that the robot can lift objects up to 11 cm and move from left to right to about 11 cm. Our robot provides improvements over various existing pneumatic muscles and grippers, giving a new idea for soft robotic combination and advancements.

Introduction

The pneumatic artificial muscle (PAM) and the universal gripper have a variety of applications from mobile robots, continuum robots, and soft robots. [1] There are many different PAM designs, and most design ideas consider a soft pneumatic bladder which can expand under pressure, causing the soft body to extend and contract to certain angles. The most widely used design is the Mckibben muscle, which uses an airtight bladder with sleeves made of intensive fibers surrounding it. [1] When the bladder is under pressure, it expands against the sleeves, causing it to contract. However, this design is limited because of its short fatigue life and stiffness.

To overcome those limitations of the Mckibben muscle, we use a new PAM made of a single layer of woven and airtight fabric (fPAM). The fabric has no stiff outer weave and a longer fatigue life, and it is often used as the materials of tents and tarps. The fabric is inextensible along the major thread lines, but elastic along the bias at 45° to the lines. This means it will function similarly to a McKibben muscle because when the fabric tube is pressurized it will expand while contracting to certain angles. [1]

On the other hand, the soft universal grippers are mostly designed to grab objects with a process called "jamming". We refer to the website article "DIY Universal Robot Gripper" by DIY Hacks and How Tos. [2] The universal grippers always include granular material wrapped in a balloon which can be pressurized. When the balloon is pressed against an object, the granular materials will take its shape and move around it. But when the pressure is released from the balloon, the granular materials will be compressed and grip the object. [2]

Considering the functions of these two soft robots, the combination of them is able to grab a variety of objects and either move horizontally or lift up to some distances.

Design

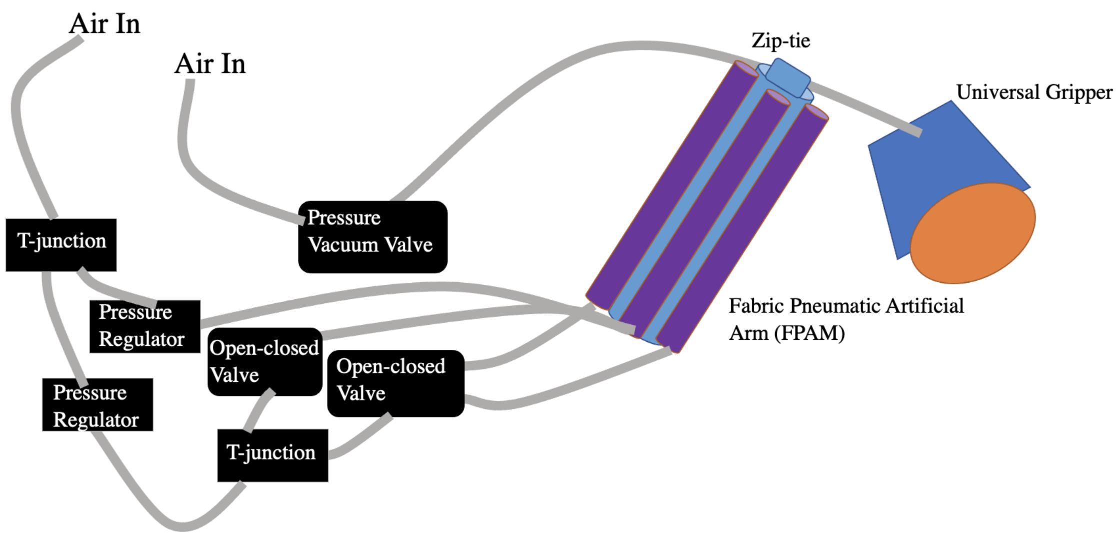

Figure. 1: Schematic modeling diagram of the gripper fPAM soft robotic system

The major theme of our design is to combine a fabric pneumatic artificial muscle (fPAM) with an universal gripper. The combined model should have the ability to pick up an object and move the object some distance to the left/right. Specifically, the fPAM has three muscles attached to the main body. The upper muscle is responsible for the up-lifting task as it gets inflated. The other two muscles on the side contract under pressure to bend the main body. The universal gripper is attached to the front end of the fPAM via a zip-tie.

A circuit is designed to connect the fPAM-gripper system. As shown in Fig. 1, the three muscles of the fPAM are connected via open-closed valves which control the contraction/deflation of the muscles. The main body is directly connected to a pressure regulator and the universal gripper is connected to a pressure-vacuum valve. While the main body is inflated, we manually hold the back end of the fPAM and inflate/vacuum the universal gripper to grip an object. Then the upper muscle is inflated to lift up the object and we can inflate/deflate the side muscles to move the object some distance to the left or to the right. Finally, we can deflate the upper muscle and inflate the gripper to put down the object.

Modeling

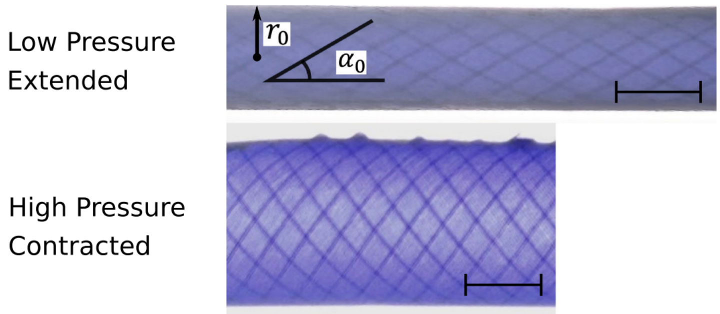

Figure. 2: Photos of the fPAM in a low pressure, extended state (top), and a high pressure, contracted state (bottom).

We refer to the paper *Simple, Low-Hysteresis, Foldable, Fabric Pneumatic Artificial Muscle* by N. D. Naclerio and E. W. Hawkes [1]. As the fPAM muscles are inflated, they are contracted as can be seen in Fig. 2[1]. As the muscle shortens, its volume increases to a maximum point determined by the braid angle α_0. This causes the muscle to contract and the contraction ratio, ε, which is defined as the muscle length over its initial length. The fPAM works in a similar manner to a McKibben muscle. For a McKibben muscle, the equation for force, F_{ideal}, as a function of contraction ratio, neglecting friction and end effects, has been derived as:

$$F_{ideal}(\varepsilon) = \pi r_0^{\ 2} P(a(1 - \varepsilon)^2 - b)$$

Where $a = 3/tan^2\alpha_0$, and $b = 1/sin^2\alpha_0$, and P refers to the internal pressure of the muscle, and r_0 is the initial, depressurized radius and α_0 is the braid angle as shown in Fig. 2.

In addition, we predict the shape of the fPAM-gripper system while at use as shown in Fig. 3. While the upper muscle is not pressurized, we suspect that the fPAM would be bending downwards. Whereas while the upper muscle is fully pressurized and assuming there is no gripper, the fPAM would be bending upwards. Superpositioning the two configurations, we hypothesize that when the fPAM-gripper system is at use and the upper muscle is fully pressurized, the model, instead of being fully flat and stiff, will have a curved configuration.

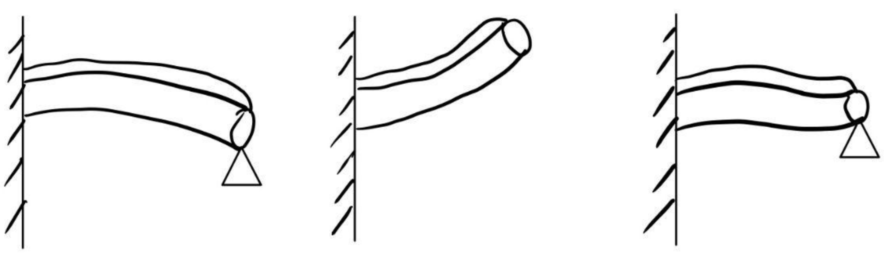

Figure. 3: Predicted shape of the fPAM-gripper system while at use/at rest

Fabrication

The fPAM tubes are only made of a bias-cut, woven fabric tube. We selected this fabric because it is thin, lightweight, and airtight. The fPAM tubes are built in 5 steps: First, a strip of fabric is cut along the bias at 45° to the length of the strip (Fig. 4-A). Second, the strip is placed on the lab ground, and a thin strip of double-sided tape is placed along its center, attaching to the ground at each end (Fig. 4-B). Third, one side of the strip is folded over and adhered to the tape, and an adhesive is placed along the fabric (Fig. 4-C). Then, the other side of the fabric is folded over and adhered to the adhesive to create a joint (Fig. 4-D,E). Finally, the tube can be everted to remove the double-sided tape after some time (Fig. 4-F). [1]

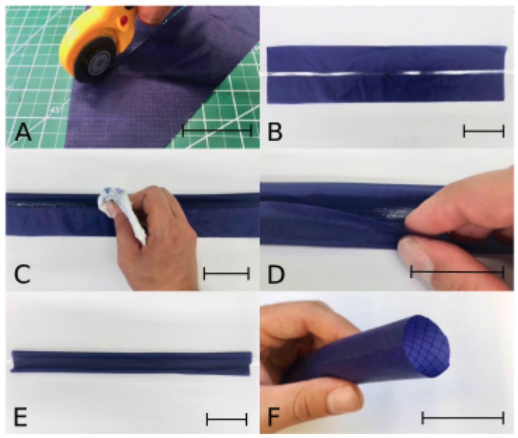

Figure. 4: Photos of fPAM fabrication steps.

By using the same method above, we made one main body tube and three side tubes of fPAM. We then used the adhesive to attach the main body and three side tubes together with each side tube distributed along the main body side equally at 120°. The side tubes were 30 cm long, and the main body tube was 32 cm long.

The universal gripper consists of a balloon, a plastic funnel, coffee grounds which are granular materials, a tape, an air tube, a small plastic tube, and a thin cloth. [2] The gripper is made in 4 steps: First, the balloon is filled with coffee grounds (Fig. 5-A). A plastic tube is connected to the end of the balloon and the plastic funnel. Then, the coffee ground is added to the balloon from the funnel. We gently blow into the tube to inflate the balloon and let all the coffee remain inside. Once the coffee ground is enough, the balloon can be removed from the tube. Second, the air tube is covered with a small cloth and taped (Fig. 5-B). Third, the tube is placed into the balloon opening and taped (Fig. 5-C). Afterwards, some fabric or cloth is inserted into the base of the balloon as a spacer to make sure the balloon protrudes beyond the surface of the funnel (Fig. 5-D). [2]

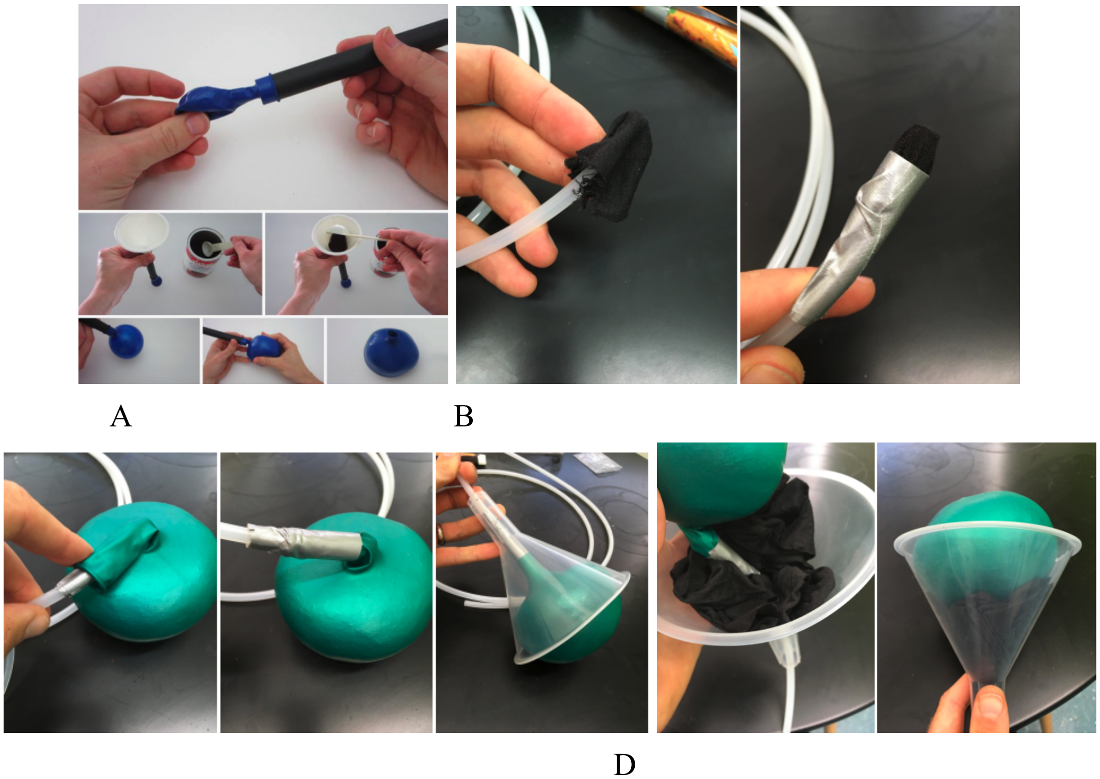

Figure.5: Universal gripper fabrication steps.

Once the universal gripper and the fPAM tubes were made, the main body tube was attached to the universal gripper by zip-ties. Then the air tubes were connected to each fPAM tube so that both the gripper and the tubes could be pressurized and operated successfully.

Results

The fPAM that we built consists of two parts: the main body and three associated muscles. The main body is 7 cm wide when inflated and 32 cm long, and three muscles are 2.5 cm wide when inflated and 33 cm long. We tested our model in a real-world scenario where we use the model to pick up an object on the desk, lift it up, and move the object some distance to the left/right. Each muscle and the main body is connected to an air tube so that it can be pressurized and inflated. The gripper is connected to a pressure-vacuum valve and zip-tied to the front of the fPAM.

We were able to pick up some small objects such as airpods, car keys using the universal gripper and lift the object up when the upper muscle is pressurized and inflated. We measured and recorded that we were able to lift the object 11 cm up from the desk. As soon as we lifted the object, we inflated the side muscles and found out that we were able to move the object 10 cm along the horizontal direction.

Compared with the shape that we predicted in the modeling section, the resulting shape showed that it did not behave quite similar to what we expected (see figure 6). The reason for this might be due to the fact that the main body of this robot was not long enough to see the curved shape.

A B

Figure.6: Actual shape of the fabric pneumatic artificial muscle with a gripper.

Conclusion

The fabric pneumatic artificial muscle with a gripper is simple, flexible, and reproducible. It integrates two soft robot functions together and improves the performance to a higher level. It not only achieves the object picking up function as the universal gripper does, but also lifts the object and moves it some distances from left to right or right to left. Future work on the fabric pneumatic artificial muscle with a gripper could include the thinning procedures of the main body to make the robot move more distances. Also, the main body can be extended to match the prediction of the modeling shape.

References

[1] Naclerio, Nicholas D., and Elliot W. Hawkes. IEEE Robotics and Automation Letters 5, no. 2 (2020): 3406-3413.

[2] Tos, D. I. Y. H. and H., & Instructables. (2017, October 16). *DIY Universal Robot Gripper*. Instructables. Retrieved March 10, 2022, from https://www.instructables.com