SOFT ROBOTICS: FIBER REINFORCED SOFT PNEUMATIC MULTIDIRECTIONAL MANIPULATORS, DESIGNING, FABRICATING, AND TESTING

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ABSTRACT

Traditional robots are made from hard materials like hard plastic or metal and consist of regular rigid mechanical parts. Using those parts has some limitations, like limited dexterity and lack of flexibility. Some of these limitations could be avoided through using a compliant material, because it has higher flexibility and dexterity. It is also safer to be in direct contact with humans. This research studies soft pneumatic manipulator (SPM) that move in multi degrees of freedom (MDOF), which makes it able to perform various functions. The study will include designing, fabricating, and testing for the range of bending and elongation. The SPM consists of three soft pneumatic chambers to reach unlimited points on its workspace through implementing bending and elongating movements. There are a lot of applications for this kind of soft actuators, like rehabilitation, underwater utilizes, and robots for surgery and rescues. Most soft pneumatic actuators provide one kind of movement, for bending, twisting, or elongating. Combining more than one kind of movement in one soft pneumatic actuator provides considerable contributions to the body of research. The SPM was controlled and tested to evaluate the achieved bending and elongating range.

Keywords

Soft actuator, Soft Robot, Pneumatic actuator.

1. INTRODUCTION

The latest advancements in the robotics field have changed from inflexible instruments using gears, pulleys, and bearings to elastic and flexible actuators [1]. One of the benefits of soft robotics is the ability to deal with delicate and sensitive items. Regular robots are less reliable to work with a person because they are made from hard materials that are subject to malfunction at any time. Nowadays, robots are involved in several fields, so establishing a safe contact with humans is necessary. Moreover, traditional robots have limited ability to handle delicate items without harming them. Soft robots provide an ideal solution to deal with human and sensitive objects. These difficulties in traditional robots can be minimized by utilizing soft actuators made of elastic materials like catalyzed silicones.

The functional part in the soft robot is the soft actuator. For that reason this research is focused on improving soft actuators with high capabilities. The working concept of the soft actuator is similar to the concept of a balloon when it is inflated. The pneumatic soft actuator is completely made out of elastic material, so it can be shaped easily when fluid inflates the cavities. There are a lot of applications for those kinds of actuators, like rehabilitation [2], underwater utilization [3], and medical robots for surgery [4], [5], [6], and [7]. Soft actuators are turning into an interesting area for research, because it helps to treat some of the traditional robots problems [8].

Additionally, it is interesting field for the researchers because they are affordable, safe, have more dexterity and not heavy. These adequacies help the researchers to use the soft robotics technology in designing some animals [9]. By taking the advantage of the compliance material that used in soft robotics, it is possible to mimic some biological organism such as fish [10], jellyfish [11], squid, octopus [12] and earthworm [13].

The research communities always focus in developing soft actuators with high capabilities because that enhance the ability of the soft robot to perform various tasks. The soft actuator made of soft material such as silicon rubber [1] and polymers [14] and that can be translated to either circular or bending motion [1]. Further, it can be designed to provide slow pnue-net or fast pneu-net [15]. There are two main outputs that evaluate the efficiency of the soft actuators which are the generated force and the end effector speed [15].

The SPM is a soft pneumatic actuator work by pumping gas or liquid into channel that blows up flexible fiber-reinforced chamber to achieve bending or elongating motion. Most of the current soft pneumatic actuators afford only one type of movement: bending, elongating, or twisting. So, it is interesting to create more than one chamber imbedded in one soft actuator to manipulate in multi-DOF.

2. METHODOLOGY

The goal of this research work is providing SPM with high capability, dexterity, and flexibility. To accomplish this goal, many trials have been applied through design and fabricate soft pneumatic actuator that can manipulate in multi degrees of freedom (MDOFs). The SPM is made of catalyzed silicone Ecoflex 50-00[16].

2.1 Designing the SPM

The design of the SPM is cylindrically and has three chambers inflate independently. The movement of the module depends on pumping air on the chambers, so that will force it to inflate and leads to bend the SPM body. Thinner faces on chambers wall subjected to high expanding and may cause undesired bubbles. To avoid that radial expansion, the outer surface of the SPM is restricted helically with fiber to force the actuator to perform bending movement. The main body for all of the SPM are made of Ecoflex 00-50 but the end closer (end effectors) are created from Dragon Skin Silicones 10 [16]. The purpose of using Dragon Skin Silicones 10 in the end closer is preventing the expansion from the end effector side because Dragon Skin Silicones 10 has higher stiffening. The mold of the main body consists of five pieces. Figure 1 show the components of the mold which are the threaded container, pneumatic template, central channel template, and base mold.

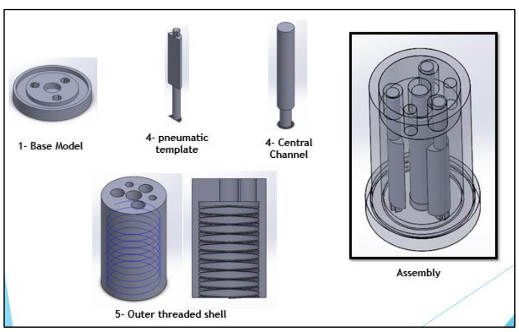


Figure 1. The components and assembly of the molds

2.2 3D Printing Molds

3D printing technology adopts to create the molds for casting the elastomer material. SolidWorks is a solid modeling computer-aided design (CAD) that used to draw and modify the SPMs and their molds. After drawing any component of the whole mold, the component is saved in STL format in order to be printed. The 3D-printer reads the STL file then generates a G code to implement the printing commands. The mold for SPM is shown in figure 2.

Figure 2. 3D printed molds

2.3 SPM Fabrication

Fabricating the SPM require six main steps; collecting the material and components, 3D printing, preparing and pouring the soft material, bonding the soft parts, wrapping the actuator with fiber thread, coating the outer surface with layer of Ecoflex 00-50, and tube insertion. The internal thread in the container mold may cause undesired tearing on the outer surface of the main body of the actuator due to its roughness. XTC-3D is an ideal product to achieve smooth surface. The threaded container, pneumatic template, and central channel template molds are placed on the base mold as shown on figure 3. The entire mold was assembled with hot glue through placing generous amount around the circumference to prevent leakage during injecting the Ecoflex 00-50. To bond the main body of the actuator and the end closer a thin layer of Dregon Skin Silicones-10 is poured over the end closer. The thread in the container mold leave clockwise and counter-clockwise groves on the SPM surface which afford guide for the fiber thread. The fiber thread will restrict the radial inflation without changing the diameter of the SPM. Then, coating a layer of Ecoflex 00-50 over the outer surface of the SPM provide stress distribution over the whole body. Additionally, this thin layer will keep the fiber thread in its place and provide a smooth surface.

Figure 3. a) put hot glue on the holes, b) pneumatic template, and central channel template molds are placed on the base mold, and c) the threaded container, entire mold was assembled with hot glue.

3. RUNNING AND EXPERIMENT SETUP

3.1 SPM Control

To run this system electronics and other components like pressure pumps, solenoid valves and microcontrollers are utilized. According to the SPM design, the three pneumatic chambers are actuating separately. Therefore, the system was created with three pumps, three solenoid valves, load cell, and three pressure sensors. The microcontroller, Arduino MEGA 2560, controls the inflation and deflation of the SPM and read the load cell and pressure sensors signals. For inflation, a constant voltage were energized the pumps, and the valves were off.

3.2 Bending and Elongating Testing

The SPM performance was tested through measuring the amount of bending angle (β) at different frequencies. Kinovea is a software that has the capability of tracking motion from saved video. The tip of the SPM module can reach unlimited points on its workspace through implementing bending movements by three soft pneumatic chambers. The Kinovea provides a planar tracking for the actuator which requires careful setting for the bending orientations. Figure 4 shows the orientations of the SPM when actuating chamber 1, 2, or 3. The SPMs will be tested in three cases; a) bending when pumping one chamber, b) bending when pumping two chambers, and c) elongating when pumping three chambers. After placing the SPM in the right position, a camera is used to recorded videos for the SPM during performing bending or elongating. The camera provides 60 frames per second that guaranteed precise drawing for the tracking paths. The camera should be exactly perpendicular to the bending axes to achieve accurate tracking measurements. Before taking the videos, a ruler was attached to the video wallpaper to calibrate the tracking workflow. Then the taken video was uploaded to the Kinovea software to measure the range of the bending in the SPM body.

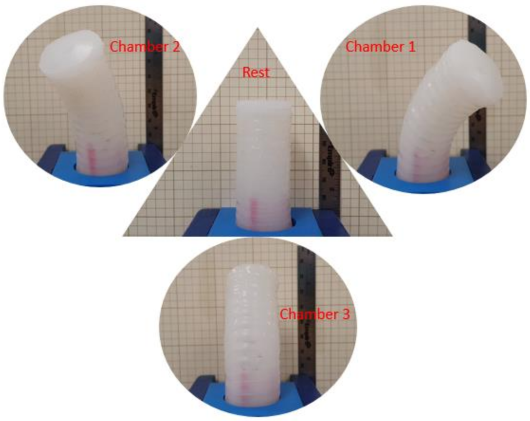


Figure 4. SPM orientations at rest and when actuating chamber 1, 2, or 3.

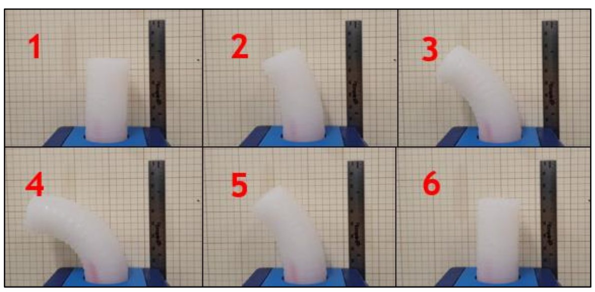


Figure 5. KINOVEA photo sequences for bending

4. RESULTS AND DISCUSSION

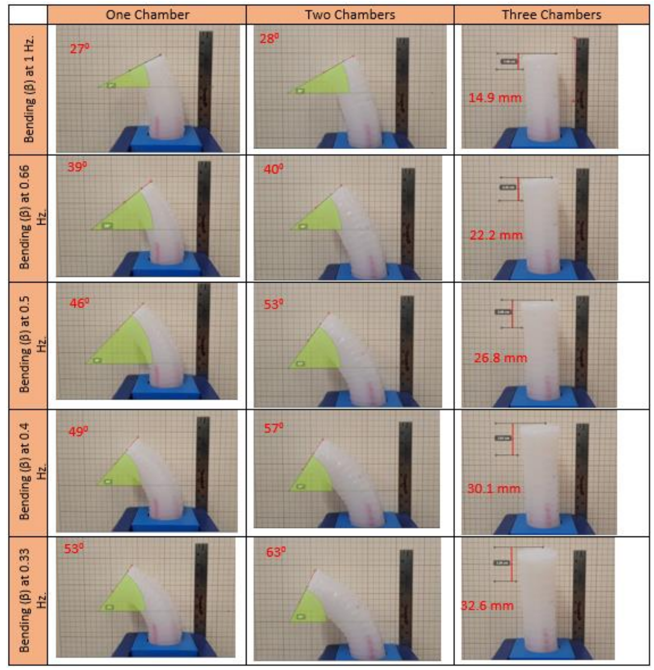
Tables 1 shows the bending angle (β) of the SPM at different frequencies, when one, two, and three chambers are actuated. Every single picture in the tables was calibrated, measured, and captured with the Kinovea software. It could be observed that the SPM perform wider bending when inflating two pneumatic chambers. Additionally, the bending angle increase as the frequency decrease because the actuator had more time to inflate. The forth column shows the elongating of the SPM at 1, 0.66, 0.5, 0.4, and 0.33 Hz. When the three chambers are actuated with the same rate, the SPM will expand vertically which cause the elongation. As expected, the SPM recorded higher elondation when actuate at lower frequency.

5. CONCLUSION

The soft pneumatic manipulators (SPM) was successfully designed, fabricated, and tested. The bending and elongating tests show that the SPM has high flexibility and dexterity which make it valuable for many applications.

Studies to develop performance and capabilities of soft pneumatic manipulators are vital for the future of soft robotics. With such researches, optimization of performance could be predicted and engineered to meet application demands

Table 1. Bending angle (β) of the SPM at 1, 0.66, 0.5, 0.4, and 0.33 Hz when one, two and three chambers were actuated.



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