Comparison of Production Methods in Soft Robotic

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Abstract: *This paper explains and compares production methods of soft robotic actuators. Soft robotic is a new area which is inspired from living creatures. Soft robots are produced from soft and elastic materials. They mainly work on the robots that operate by the use of pneumatic and dielectric structures. Basically there are four methods. These are Pneunets bending actuators, fiber reinforced actuators, pneumatic artificial muscles and dielectric elastomer actuators. We compared four type of actuator according to material that are used in the actuator body, additional material that are used in application, number of production steps, the number of equipments, reproducibility and actuator functions. The most determinative topics for usage of the actuator are reproducibility and actuator functions. Reproducibility effects on speed of after productions that means first fabrication process may be slow but following production of same products will be much faster. These four types of actuators are briefly summarized in a table. According to this table the most useful actuator type is fiber reinforced. These types of actuators have three types' functions (bending, twisting, extending) and also we can use combine of these functions and one of the advantages of these type of actuator is not requiring any assist component.*
Key words: *soft robotic, robotic actuators, production processes.*

1. Introduction

Today robots are generally used in factories. These robots can be perfect in limited tasks in controlled environments but sometimes they can be unsafe some environments which include human. The production of conventional robotic systems relies on the use of rigid and hard materials. Therefore, conventional robotic systems are appropriate for heavy work and difficult tasks. However, these systems are far removed from bio mimicry so they are less in accord with organisms. For instance, wearable robotics and surgical robotic applications which work with organisms and tissues might harm these structures. Because conventional robots are less adaptable to the environment there has been an increase in the number of studies which were conducted on the production of robotics by using soft and elastic materials. These researches have produced soft robotic area.

Soft robotic is an area which is produced by soft and elastic materials mainly works on the robots that operate by the use of pneumatic, hydraulic and dielectric structures. With the aim of the methods that are used for soft robotic design many robots have been developed in order to be used in biomedical, defense, industrial, educational applications and emergency cases [1],[2],[3]. These robots consist of a combination of various elastic and soft materials in layers and cells. Therefore, soft robots are lighter and consume less energy and nature-friendly [4], [5], [6].

Chou et.al.(2009) describe soft robots as they use soft and compliant materials and they are manufactured by nontraditional processes [6]. Sphered et al. (2011) touched on soft robots composed of soft materials elastomeric polymers), which is inspired by animals that do not have hard internal skeletons [7]. Briefly Soft robotic is an area which is produced by soft and elastic materials.

Soft robot's the most common application area is biomedical applications, because of the conformity of human centered tasks. Examples of the biomedical applications are given. Toshiro (2005) developed some types of pneumatic rubber artificial muscles and applied them to human friendly soft mechanisms and wearable power assist devices [8]. Rocon et.al. (2007) studied on design and validation of a rehabilitation robotic exoskeleton for tremor assessment and suppression [9] [10]. Tondu et.al.(2005) designed a seven degree of freedom robot

arm driven by pneumatic artificial muscles for humanoid robots [11]. Chou and Hannaford (1996) reported mechanical testing and modeling for the Mc Kibben artificial muscle pneumatic actuator and they compared the results with human muscle properties for using in robot arms [12]. Kim et.al. (2013) mentioned a bioinspired evaluation in robotics [13], [7]. Polygerinos et.al.(2013) designed a glove with pneunet actuators for hand rehabilitation [14]. Maeder-york et.al.(2014) designed a fiber reinforced actuator for thumb rehabilitation [2]. Liu et.al. (2013) introduced the dielectric elastomers and explained their usage areas such as dielectric actuators, artificial muscles [15]. Ogura et.al.(2008) designed a micro rubber pneumatic actuator and they explained the application areas such as medical, biotechnology and invasive surgery [16].

The other application examples of the soft robot examples are given. Onal et.al. (2011) develop soft actuators fabricated from elastomer films with embedded fluidic channels. They describe a new soft mobile robot and demonstrate its locomotion. Specifically, they report on-demand pressure generation by the mechanical self-regulation of the decomposition of hydrogen peroxide (H_2O_2) into oxygen (O_2) gas in a closed container [17]. Luo et.al. (2004) described design and dynamic analysis of a new generation of fluidic elastomer actuators (FEAs) that offer bidirectional bending developed as motion segments of a pressure-operated soft robotic snake [18]. Correll et.al.(2014) developed a class of soft mechanisms that can undergo shape change and locomotion under pneumatic actuation [19]. Luo et.al. (2014) explained the theoretical dynamic model of a soft snake robot made of silicone rubber, provided simulation results, and verified the effectiveness of the model through a detailed comparison with experimental results on the locomotion of the robot on a surface [20]. Onal and Rus (2013) developed an autonomous soft snake robot with on-board actuation, power, computation and control capabilities [4]. Marchese et.al.(2013) studied at an example case-study: a soft robotic fish [5]. Seok et.al.(2013) studied on a peristaltic soft robot with antagonistic nickel titanium coil actuators [21].Lipson (2014) mentioned new opportunities in soft robotics and some potential avenues to overcome challenges associated with realization of these opportunities [22]. Bahramzadeh and Shahinpoor (2014) reviews ionic polymeric soft actuators and sensors [23].

Marchese et.al.(2014) studied on an autonomous soft robotic fish capable of escape maneuvers using fluidic elastomer actuator [24]. Stokes et.al.(2014) used a hybrid combining hard and soft robots in their study [25].Majidi (2014) explained current trends and prospects for the future [26]. Laschi et.al. (2012) studied soft robot arm inspired by the octopus [27]. Lu and Kim (2014) researched about flexible and stretchable electronics for soft robotics [28]. Kovac (2014) explained about bioinspiration design for soft robotic design examples, these are flapping wings, sensitized robotic skins, insect inspired compound eyes [29].Galloway et.al. (2013) studied the design and fabrication of a fiber reinforced soft bending actuator and they want to customization this for grasping applications [30]. Pelrine et.al. (2001) mentioned the other types of actuators , dielectric actuators. They explained the advantage of the dielectric elastomers' in converting mechanical to electrical energy in generator mode [31]. Shepherd et.al. (2011) constructed a soft robot with four leg which is controlled by pneumatic actuation and made by silicone rubber Morin et.al. (2012) mentioned the camouflage and display for soft machines which is inspired by color changing animals [27]. Mosadegh et.al. (2014) mentioned advantages of the elastomeric actuators which is powered pneumatically , these advantages are lightweight, inexpensive and easily fabricated [32].Doumit et.al. (2009) explained the analytical modeling and experimental validation of the braided pneumatic muscle [33]. Sun et.al. (2013) made the characterization of silicone rubber based soft pneumatic actuators and their study is the basis for designing customized soft pneumatic actuators with application specific- requirements [34]. Wissler and Mazza, (2007) reported an experimental work about dielectric elastomer actuators and they examined the mechanical behavior of an acrylic elastomer used in dielectric elastomer actuators [35].

2. Production Methods Of Soft Robot

Soft robots are composed of various actuators. Actuators can be divided into four classes according to their muscles, dielectric elastomer actuators.

2.1. PneuNets bending actuators

PneuNets bending actuators include a series of channels and chambers inside an elastomer. These channels provide the movement of the actuator. When pressure is applied to chambers, they expand. Cases of the affecting the movements of the actuator are briefly summarized:

Production Steps of a PneuNet Actuator

- Preparing the mold by 3d printer : Two parts of mold is designed by solidworks cad program and print in 3d printer. One of the mold is body mold, the other is cover mold.
- Preparing elastomer: Silicone rubber elastomers occur two part. These two parts mixed in a certain ratio. Using equipments while preparing the elastomer are mass scale for measuring the elastomer weight and centrifugal mixer for mixing.
- Pouring elastomer: Prepared mixed silicone rubber pours in to body mold and puts in to vacuum chamber for destroying the bubbles in the elastomer. After de-gassing treatment elastomer put in to lab oven at 65 °C for 10 minutes [18], [36].
- Assembling actuator: Elastomer is separated from the mold and assembled to form actuator.
- Connecting air source: Finally air source is connected to elastomer actuator body [36].

2.2. Fiber Reinforced Actuators

Basic structure of fiber reinforced actuators consist of an elastomer bladder and covering an inextensible reinforcements [36]. These reinforcements especially can be a textile surface such as Kevlar thread and glass fibers etc [2], [30], [36]. A general fiber reinforced actuator figure as you can see in below (see in fig: 6). Strain wrapping and strain layer guides the motion of the actuator, such as grasping, twisting, extending.

Production Steps of a Fiber Reinforced Actuator

- Preparing the mold by 3d printer: This step is the same with pneuNet actuators'. Three parts of mold is designed by solidworks cad program and printed in 3d printer.
- Preparing elastomer: The same with pneunet actuators.
- Pouring elastomer: The same with Pneunet actuators. After Curing the elastomer in the molds, elastomer separates from the molds.
- Adding strain limiting materials: Glass fiber is added to bottom of the elastomer actuator body to provide grasping. Kevlar thread is wrapped to elastomer actuator all of the body for strain limiting.
- Encapsulating the elastomer body: After wrapping , the elastomer body should encapsulate in the same molds for protection of the body.
- Plugging one end : After curing the body one of the end of actuator should plug.
- Installing vented screw: Piercing the plugged end by thin road and sticking out the far end of actuator for air source.
- Capping other end and attaching air source Elastomer actuator body is capped and attached it air source [36].

2.3. Pneumatic artificial muscles

The first example of Pneumatic artificial muscles is Mc Kibben air muscles. McKibben air muscles were invented for orthotics in the 1950s. They have the advantages of being lightweight, easy to fabricate, are self limiting (have a maximum contraction) and have load-length curves similar to human muscle [24], [31], [32].

Tondu (2012) explained the working principle of Mc Kibben that is very simple: The circumferential stress of a pressurized inner tube is transformed into an axial contraction force by means of a double-helix braided sheath whose geometry corresponds to a network of identical pantographs [38][36].

Production Steps of a Pneumatic Artificial Muscle

- Inner tubing: Inner tube can be made the similar way of pneumatic fiber reinforced actuator elastomer body, but practically it can be a party ballon for the inner bladder.
- Preparing braided mesh: In this step , braided mesh's end clamps with lock nut.
- Adding mesh and finishing: In this step molded tube is inserted in to the mesh and the actuator is coated [36].

2.4. Dielectric Elastomer Actuators

A dielectric elastomer actuators consists of a soft, prestretched, dielectric membrane that is attached to a rigid circular frame [36].

Production Steps of Dielectric Elastomer Actuators

- Prestretching of the membrane onto the rigid frame.
- Painting of the active area with carbon grease.

- Application of copper leads
- Connecting active area with copper tapes [36].

3. Comparison Table and Parameters

TABLE I: Comparison Table

Method	Materials and Additional Materials for Application	Number of Production Steps	The Number of Equipments	Reproducibility	Actuator Functions
PneuNets Bending Actuator [16],[14],[32],[34],[20]	• Silicone rubber • Pneumatic tubing/hose • Piece of office paper • Pump • Control circuit • Power source	5	8	Easy: No steps requiring dexterity.	• Bending
Fiber-Reinforced Actuators [30],[2],[7]	• Silicone rubber • Silicone sealant • Textile surfaces(for fiber reinforce) • Pump • Control circuit • Power source	8	8	Normal: 1 step requires dexterity. (4th step)	• Bending • Twisting • Extending
Pneumatic Artificial Muscles [37],[12],[33],[11]	• Elastomeric inner bladder • Braided outer mesh • Clamps • Pump • Control circuit • Power source • Rigid components	3	1	Hard: 3 steps require dexterity.	• Pulling
Dielectric Elastomer Actuators [31],[15],[35]	• VHB tapes • Acrylic • Carbon grease • Copper tape • Control circuit • High voltage(kV) power source	4	1	More Hard: 4 steps require dexterity.	• Pulling • Pushing

In this section we clarify the topics in the table we used and read table what it wants to tell. These are briefly as below;

- Materials: used raw materials in production of actuators.
- Materials for Application: Additional materials for applications.
- Number of Fabrication Steps: Number of steps and stages of production.
- Number of Equipments: Number of equipments used in production steps.
- Reproducibility: Reproducing same actuator by anyone with same equipments and materials under the same conditions. Reproducibility effects on speed of after productions that means first production process may be slow but following fabrication of same products will be much faster.
- Actuator Functions: abilities of actuators after production.

4. Conclusions

As a result of the literature reviews we compare the four types of actuators according to their material that are used in the actuator body, additional material that are used in application, number of production steps, the number of equipments, reproducibility and actuator functions.

All of the soft robots are produced by soft materials but there isn't any system which is completely soft. In all systems even if actuators can be completely soft, but all additional components are rigid.

Pneunet bending actuators is the most reproducible actuators , but they have minimum functionality. According to production steps, generally an actuator which has more steps has more function seems.

The most determinative topics for usage of the actuator are reproducibility and functions. According to these topics the most useful actuator type is fiber reinforced. This type of actuators have three types functions and also combine of these functions and one advantage of these type of actuator is not requiring any assist component.

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