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SOFT ROBOTICS: STATE OF ART AND OUTLOOK

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ABSTRACT

Widely used robot systems have a rigid base structure that limits the interaction with their environment. Due to the inflexible attachment points, conventional robotic structures can only manipulate objects with their special gripping system. It can be difficult for these systems to grasp objects with different shapes, handle complex surfaces or navigating in a heavily crowded environment. Many of the species observed in nature, like octopuses are able to perform complex sequences of movements using their soft-structured limbs, which are made up entirely of muscle and connective tissue. Researchers have been inspired to design and build robots based on these soft biological systems. Thanks to the soft structure and high degree of freedom, these soft robots can be used for tasks that would be extremely difficult to perform with traditional robot manipulators. This article discusses the capabilities and usability of soft robots, reviews the state of the art, and outlines the challenges in designing, modelling, manufacturing, and controlling.

Keywords: soft robotics, soft actuators, bio-inspired robots, pneu-net, flexible robots

1. INTRODUCTION

Engineers have been studying the mechanics of biological systems for a long time and that always been a great source of inspiration for them. Softness and adaptability are outstanding properties of the biological systems, tend to strive for simplicity and show reduced complexity in their interactions with the environment. Based on these biological systems, a new class of machines was defined as soft robots [1][2]. These systems contain soft elements instead of a rigid structure, allowing them to perform tasks that conventional robotic systems would not be able to perform. Conventional, rigid robots are widely used in manufacturing today and can be used with high efficiency to efficiently perform a single well-defined task. However, their adaptability is very limited as they consist of rigid bonds and joints, so their use in a changing environment poses many problems. Soft robotics allows to design systems that adapt to the environment and unspecified events with great efficiency. These features open new opportunities for machine-human collaboration and the development of autonomous systems

2. COMPONENTS OF SOFT ACTUATION

2.1. Materials and power sources

Soft materials are key to creating a soft robot. The elasticity of the materials is described by the Young's modulus, but it is only defined for homogeneous prismatic bars subjected to axial loading and small deformations. Nevertheless, it is a useful measure of stiffness for materials used in the manufacture of robotic systems. Materials used in robotics (e.g., metals, hard plastics) have a modulus of the order of 10^9-10^{12} Pa, while natural organisms often consist of materials (e.g., skin, muscle tissue) with a modulus of the order of 10^4-10^9 Pa [2]. Soft robotics defines systems that consist primarily of materials whose modulus falls within the modulus of soft biological materials.

The power supply systems required for their operation are a major challenge for soft robots. These systems are usually able to operate using 2 types of energy: pneumatic and electrical. For pneumatic actuators, the existing power sources are not soft and are usually large. Pressure sources available from the current shelf are usually limited to compressors or pumps [3]. Compressors convert electrical energy into mechanical

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energy, and compressed gas cylinders store a certain volume of pressurized fluid so that it can be discharged when needed.
Electrically driven actuators require a soft, flexible, lightweight power source [4]. Soft electronics, like soft robotics, are one of the most active research area.

2.2. Actuation

The easiest way to create a homogeneous load on a deformable piece of material is to increase the applied pressure with the aid of a liquid medium. This concept is the core of many soft actuators and their various implementations. The simplest soft actuators include blisters that can be rapidly inflated with compressed air to generate the mechanical effect that creates displacement. If a specific spatial architecture is developed for the bladder, one direction of expansion may be preferred over the others and as a result, different types of motion can create (see Figure 1.). In addition, folds can be added to the design, allowing movement to follow prescribed paths [5][6].

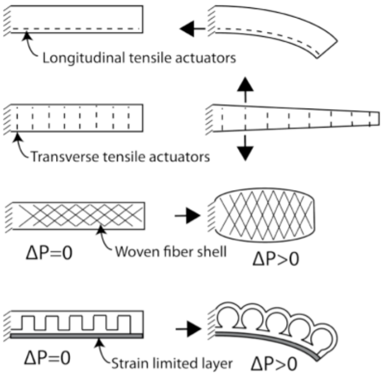

Figure 1: Common approaches to actuation of soft robot bodies in resting (left) and actuated (right) states [2]

Soft robot segments are generally operated by inflate channels in soft material and this achieve the desired deformation. Pneumatic artificial muscles (PAMs), also known as McKibben actuators, are examples of suitable linear soft actuators consisting of elastomeric tubes in fibrous sheaths [7].
Fluid elastomer actuators (FEAs) are a new type of highly extensible and adaptable low-power soft actuators. FEAs are synthetic elastomers operated by dilating embedded channels using pressure. The FEAs can be operated pneumatically [8] or hydraulically [9].
While most soft robots use pneumatic or hydraulic actuation, researchers are also focused on the development of electrically operated soft actuators, which used electro-active polymers (EAPs). These actuators include dielectric EAPs, electrostrictive graft polymers, and stimulus-responsive gels [10].

3. FABRICATION OF SOFT ROBOTIC STRUCTURES

3.1 Molding

The vast majority of soft structures are made of a catalysed polymer, such as silicone rubber, which is prepared by mixing two components prior to casting operations. However, the homogenization steps add air bubbles to the mixture and these bubbles can cause weaknesses in the final structure. These should be removed, usually by vacuum degassing of the mixture or alternatively by rotating the mold and using centrifugal forces [11].

The most difficult part of making a mold is that cavities have to be left in the internal structure, so the usual manufacturing methods are out of the question. The simplest solution to the problem is to cast the part from several parts, which can then be sealed together by gluing or dipping the parts into an unbound material [12]. However, the seam obtained by this method may be structurally weak.

3.2 Additive manufacturing

In contrast to classical machining methods, also called extraction manufacturing, where the tool removes material from a workpiece to produce the desired shapes, additive manufacturing (AM) is based on the local deposition of a small amount of material to form the shape. The available technologies have been constantly improving since the early 1990s [13], so it is now possible to create components from polymers and elastomers, metals, ceramics, and in some cases even to combine or mix two or more building materials.

The most commonly used method for AM is the fused deposition modelling (FDM) procedure. In this case, the 3D shape is formed by sweeping each layer with a thermoplastic extrusion nozzle to form a thin polymer fiber [14].

4. APPLICATIONS

4.1. Location changing

In soft robotics, there is a great opportunity to design systems that are able to change their own location. Most of the research is based on the movement of animals whose muscles and tissues can be modelled with soft robotic elements such as e.g., caterpillar [15] [16], octopus [17], fish [18]. These systems can diversify depending on the number of the soft actuators and their design (see Figure 2.). Various forms of movement can be produced with soft elements such as: four-legged movement [19], rolling [8], snake-like waving [20] and jumping movement [21].

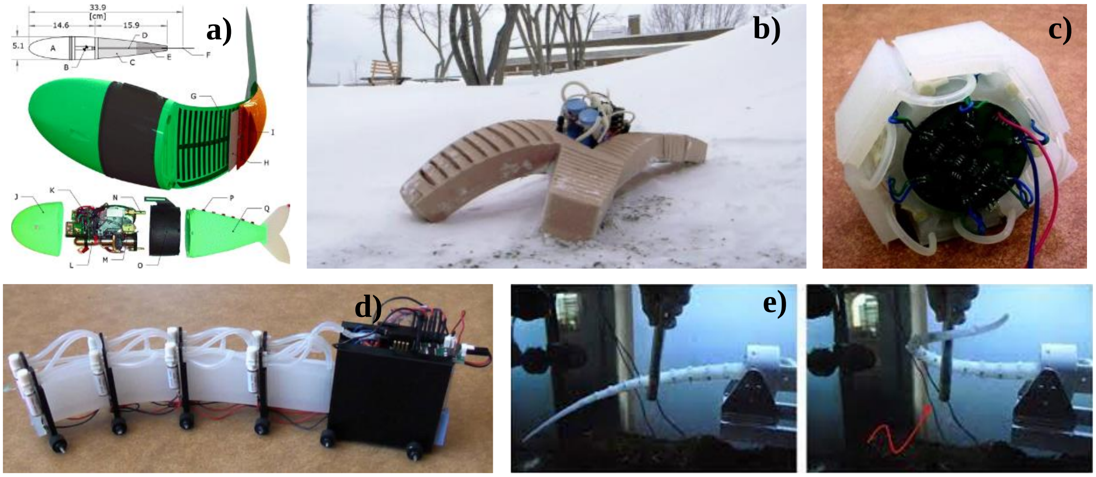

Figure 2: Soft robot systems of different designs. a) hydraulically operated soft robot [18], b) four-legged autonomous soft robot[19], c) rolling soft system [8], d) meandering soft unit [20], e) octopus arm like soft actuator [17]

The typical operating power sources (e.g., air compressors, batteries) are relatively heavy, so this greatly simplify the system design by significantly reducing load capacity. One approach to implementing mobile systems is to connect a soft robot to a mobile rigid robot with higher load capacity [22] and the other approach has developed materials and designs that are designed to operate at high pressures to transport payloads [19].

4.2. Manipulation

Manipulation is one of the most exciting challenges in robotics. Soft systems have a natural advantage over rigid robots in manipulating unknown objects (see Figure 3.). Due to the soft grippers, it is possible to adapt to different objects with simple control schemes [23]. Grippers used in isothermal systems can take of this advantage over conventional rigid manipulators [24] and this silicone elastomers demonstrate impressive adaptability thanks to embedded pneumatic channels [25][26].

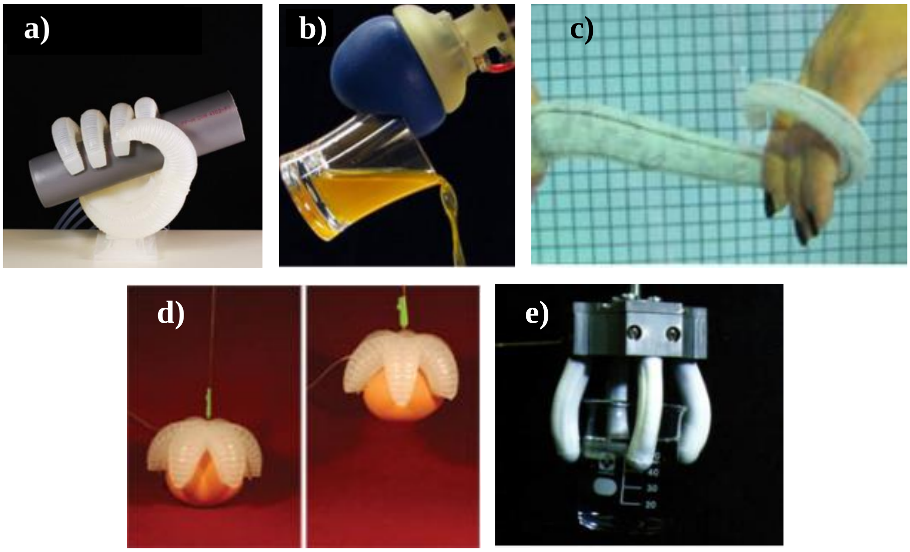

Figure 3: Soft grippers of different designs. a) hand shape gripper [25], b) jamming based manipulation [24], c) octopus arm like soft gripper [17], d) 6 segment gripper [23], e) microactuation manipulation [26]

4.3. Wearable applications

One of the natural advantages of soft robotic systems is that their wear does not restrict limb movement due to the flexibility of their modules. For rigid medical devices or orthoses
there is a risk that wearing it uncomfortably may damage human tissue. One option is integrating a degree of fitness into wearable devices such as orthopedic rehabilitation. Recently, researchers have begun to study soft wearable medical applications (see Figure .4), including soft orthodes for human ankle-foot rehabilitation [27], hand rehabilitation [28] and soft sensing suits for measuring lower extremities [29].

Figure 4: Wearable soft robotic devices. a) ankle rehabilitation with soft actuator [27], b) soft robotic glove [28], c) soft sensing suit [29]

5. CONCLUSIONS AND PERSPECTIVES

Soft robotics is a relatively new area of research. A wide range of systems have already been developed with a number of applications but there is still plenty of scope in many disciplines. The development of technology is closely linked to the development of new manufacturing techniques, enabling the production of increasingly complex devices that can facilitate the production of soft systems. The introduction of new innovative materials such as self-healing polymers or biocompatible elastomers will also lead to a further expansion of soft robotics in medical and biomechanical applications. Current manufacturing technologies already allow for the widespread use of soft robotics and these opportunities will evolve with the development of many scientific communities approaching soft robotics.

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