

Review of Dielectric elastomer based application for Soft robotics

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Abstract. Soft robotics is a growing field that is getting more and more attention. Unlike traditional rigid robots, soft robots have a simpler structure and control logic, a simple electric voltage change can activate the whole control system, with the capability of carrying out more complex tasks at the same time. Dielectric elastomer is thought to be a fundamental technology advancing the development of soft robots, with the advantages of fast response, great stretch capacity as well as resilience, less weight and higher energy density. Dielectric elastomer technology has many practical applications, such as grippers, robots on ground, swimming robots, artificial body tissues and so-called artificial muscles. In this paper, we mainly introduce the state-of-art application of Dielectric elastomer in the soft robotics field and also discuss the challenges that the DE-based soft robotics are encountering.

Keywords: Soft Robots, Soft Actuators, Dielectric Elastomer, Swimming Robots.

1. Introduction

Compared to traditional rigid robots, soft robots are more like a baby learning how to walk for the first time. For rigid robotics, they are first being proposed and designed to help humans get rid of repetitive tasks such as picking and moving a uniform object from one place to another [1], therefore, rigid robots are generally designed into a robust mechanical construction in order to protecting the important cores such as sensors, computation system. Moreover, tasks such as welding and mentor cutting are dangerous for operators, rigid robots are also responsible for preventing people suffer from unknown dangers. Control system of the rigid robot is well developed during these decades, with the demands mentioned above, rigid robotics system is designed into a tethered system, which indicates that the main structure of the robot is stationary on the ground in certain space. The control system is generally autonomous, which were wished to carry out the predetermined tasks without disturbance from the external environment and human. With reliable mechanical design, multiple degrees of freedom and each joint giving the possibility of achieving more complex movements. However, the complexity of the motion leads to another problem, which is durability. Repetitive motions can have an impact on the rigid structure, especially for the connections of actuators which need to be moved frequently. Furthermore, a complex structure and control system means that each movement of energy cost would become intensive and thermodynamic inefficient. Without proper maintenance, the robots will be soon unusable, which also leads to an expensive cost for repair.

Obviously, rigid robots are not suitable for daily use, more specifically, it is not suitable in household or any other occasion that required close contact with fragile objects such as eggs, vase, glasses, human skin and so on. In these occasions, although rigid robots can still perform their ability to handle such tasks, it is more complicated than what we consider. When handling an unknown object, rigid robots need to utilize multiple sensors to estimate the surface and the surrounding of the objects, then by computing the pressure and distance to make sure each output force are accurate in order to preserve the objects,

Above are the difficulties that rigid robots are currently facing. And this is the reason why soft robots have been proposed and developed during these decades, problems mentioned above need to be solved and explored by redesigning another robot made of soft materials. Soft robotics is a new discipline that combines various technologies from materials science, chemistry and robotics. The exploration and research of soft robots stem from the search for bio-compatible and human-robot interaction. Compared to rigid robots, robots made of soft materials have the advantages of lightweight, simple structure and control logic, and low energy consumption. In addition to this, due to the special properties of soft materials, some of the active materials will deform under external stimulation such as red light and temperature [2], however, such deformation is reversible, and soft robots can also realize extraordinary operations, such as curling and extending, some research even proposed the concept and application of self-adaptation through utilizing the characteristics of soft material [3].

In order to develop the functionality of soft robots, drive technologies have been proposed during these years. For soft robotics, the intensity of materials determines the upper limit, scientist are desired to find out an efficiently controllable active material, besides the stimulation we mentioned above, we also have pH and electric stimulation, which are considered might not be easily influenced by the external environment but manipulation.

Dielectric elastomer was proposed as a kind of electric-active polymer, which are the widely used in the soft robotics field, with the intelligent performance of faster response, lower density, and high energy density compared with other material such as shape memory material (SMAs) and other metal composites. Moreover, one of the biggest advantages is its simple working mechanism, from figure 1, we can clearly see that while we input external voltage into the dielectric elastomer-based actuator, Maxwell stress would do impact on the elastomer-area thickness, which deforms the former one. Dielectric elastomer is not only used to develop actuators such as grippers and artificial muscles but also sensors like wearable devices[4] and energy collector[5-7]. In this paper, we mainly focus on applications based on dielectric elastomer for soft robotics, which will be introduced in the next part, including grippers, robots on ground and under-water and also artificial muscles.

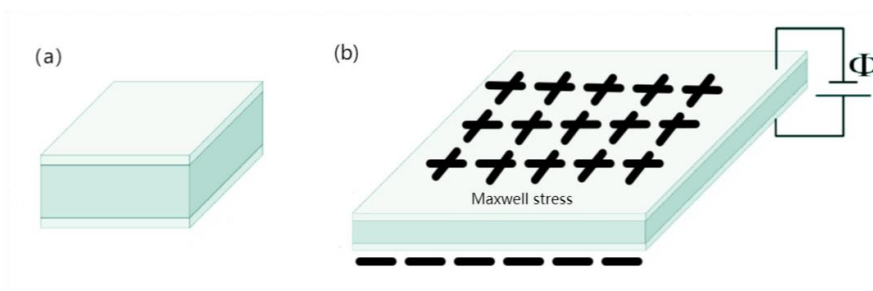


Figure 1. The Working mechanism of a dielectric elastomer based actuator. (a) Common state, no force or voltage is applied to the actuator. (b) Activate state, external force or voltage is applied to the actuator

2. Application to soft robots

Most of the applications for soft robotics are inspired by the imitation of living creatures, such as the crawling of worms, the swimming of jellyfish, the grasping of octopus, the movement of human biceps, etc[8]. With the development of dielectric elastomer, more applications have been proposed in the past few years. In this part, we have collected the three most common types of applications, which is grippers, robots and artificial muscles. These applications illustrate the benefits of dielectric elastomer for soft robotics.

2.1. Grippers

Grasping is a repetitive movement in our daily life, so gripper is one of the most popular applications for the dielectric elastomer based actuators. In the early studies, some grippers were

developed based on the inspiration from human fingers, there is a stretched dielectric elastomer embedded in the flexible construction named the minimum energy structure [9]. As shown in figure 2 (a), Kofod, et al [10] invent a kind of gripper with three fingers based on this, when the voltage is applied to the actuators, the gripper would keep in an open status, otherwise, the gripper can grab and manipulate the object. Another finger gripper proposed by Li et al [11] is consist of a compressed spring with a stretched dielectric elastomer wrapping around, in order to support the whole structure, the spring is previously compressed through the caps at both sides, as shown in figure 2 (b), the spring-roll actuator are able to bend when applied 6kV voltage. With the development of grippers, researchers soon find out some interesting and innovative ways to optimize them by utilizing the characteristics of the dielectric elastomer, which is self-adaptive to the surface of objects that it grabs, as shown in figure 2(c), a cup-shape gripper was proposed by Canada scientists S. Pourazadi et al[12], unlike traditional grippers, the geometries of the objects are not required to know, a special mechanical design consisted of a hollow cylindrical chamber with dielectric elastomer membrane allow it to automatically adapt the shape of the objects. As shown in figure 2 (c), we can clearly see that with the high voltage applied to the dielectric elastomer, the reduction of thickness leads to the inflation of the membrane, which forces the membrane to grasp the surrounding objects. Although dielectric elastomer-based grippers have a lot of advantages when compare to rigid grippers, they still have some visible weaknesses in the practical application, which is not suitable for grasping a heavy object. Then scientists from Japan Witchuda et al [13] proposed a study on the relationship between the number of dielectric elastomer layers and the performance of their grippers, as shown in figure 2 (d), the final result of the experiment indicated that multi-layered dielectric elastomer can improve the grasping ability of grippers.

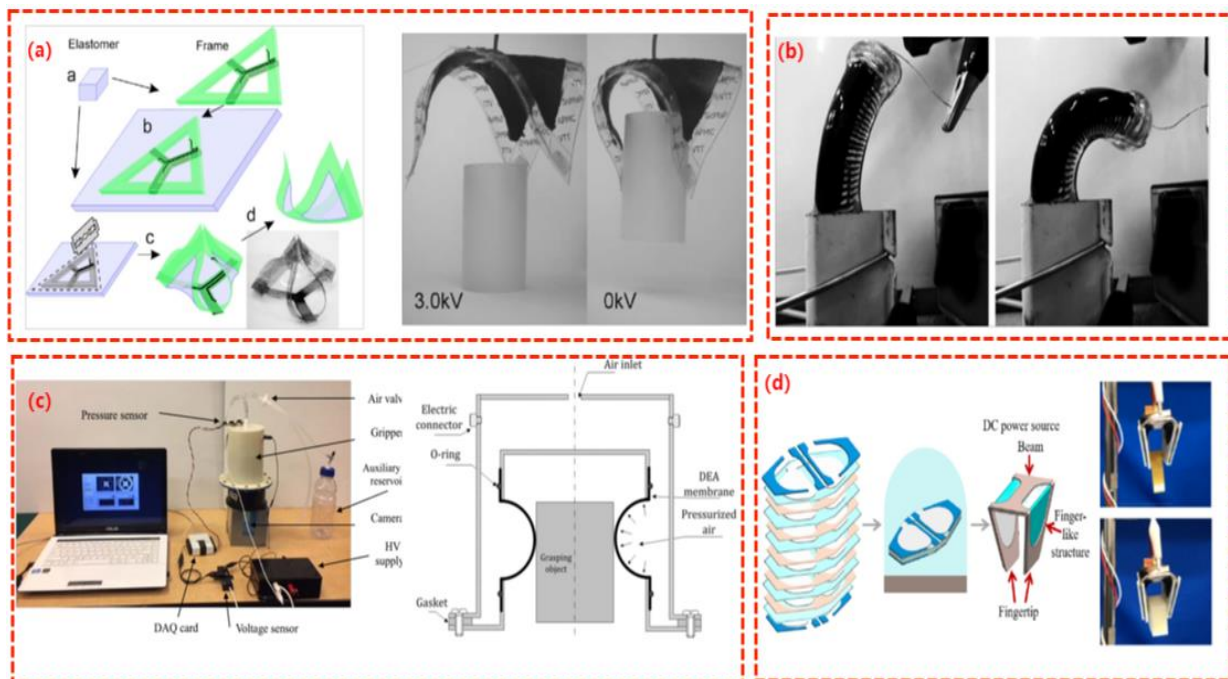


Figure 2. Dielectric elastomer based gripper (a) Dielectric elastomer embedded in the flexible construction, the minimum energy gripper (Reprinted from [10], with permission). (b) The spring-roll finger gripper, is able to bend with 6kV voltage (Reprinted from [11], with permission). (c) Self-adaptive cup-shape gripper (Reprinted from [12], with permission). (d) The relationship between the number of dielectric elastomer layers and the performance of the gripper. (Reprinted from [13], with permission).

2.2. Ground Robots

Mobility is the fundamental ability of terrestrial creatures, recent studies proposed some applications of ground robots based on dielectric elastomer which can carry sensors and cross

unknown terrain. Inspired by natural creatures, most of the research is focus on the motion including crawling as well as legged-walking, which are mainly introduced in this part.

Some research indicated that worms have the similar structural properties with dielectric elastomer, so crawling is considered one of the efficient ways for soft robots. As shown in figure 2(b) and figure 3(a), inspired by the inch-worm, Li et al. [11] developed a crawling robots base on their spring-roll actuator, it could be considered as an individual part of the three finger grippers that they proposed before, which could move similarly to a worm under the stimulation of a sinusoidal voltage. The speed of the crawling motion could reach 26.3 mm per second. For dielectric elastomer based soft robots, anisotropy and Sub-kV drive-voltage limit the performance of each motion, Xiao et al [14] reported a facile method to manufacture dielectric elastomer films of co-polymer, and then they proposed a crawling robot which could move reversibly on the ground under the applying voltage of 800V. As shown in figure 3(b), this kind of anisotropic DE crawling robot can move reversibly. With the demand of carrying out more complex tasks smoothly, and also, for the purpose of improving the mobility of biomedical legs, we need to add more degree of freedom for the actuators which are responsible for supporting the whole body structure as well as maintaining the speed and directions, which are commonly developed in so-called hexapod robot. As shown in figure 3(c), Canh et al. [15] proposed a multiple degrees of freedom DEA soft robot, which could provide a faster speed than the crawling robot significantly. Their work indicated that by embedding the dielectric elastomer into robots' structures, we can improve the performance of the mobility. In the future, they will continuously improve the actuation performance such as the speed and tuning ability of the proposed robot.

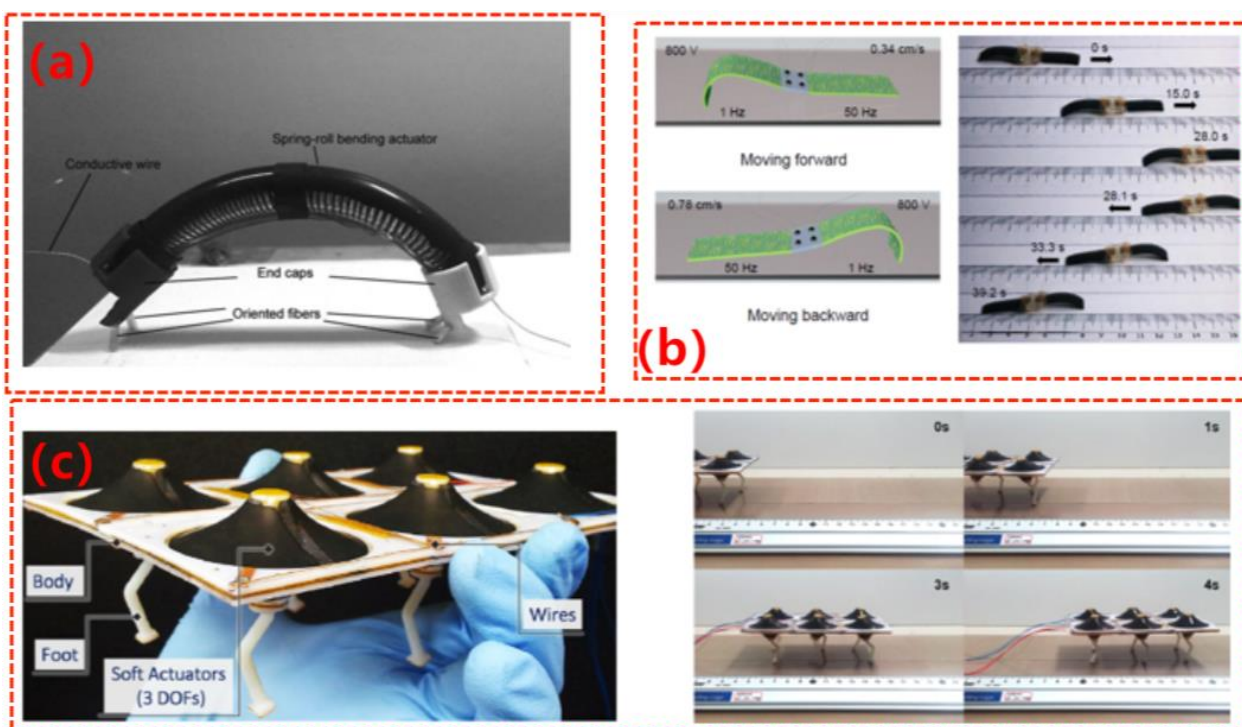


Figure 3. Dielectric elastomer based Crawling robot (a) Spring-roll crawling robot (Reprinted from [11], with permission). (b) Anisotropic crawling robot (Reprinted from [14], with permission). (c) Multiple-Dof hexapod robot (Reprinted from [15], with permission).

2.3. Swimming Robots

Benefit from the properties of soft, dielectric elastomer is very convenient to apply its strength under the water. Inspired by the creatures such as jellyfish, starfish, Manta fish etc. A lot of fish-shape DE based soft robots are applied into the water for ocean exploring. As shown in figure 4(a), Jun et al.[16] proposed a fish-shape of mixture with rigid structure (silicone layers and dielectric elastomer, with BCF(body and caudal-fin locomotion mechanism and DE working mechanism that we

introduced above, the fish-like robots are able to generate undulation and force around its body, and then swim forward exactly like the fish. Two recent applications based on the movement of jellyfish are proposed by Caled et al.[17] and Keita et al.[18].The former proposed a kind of vertical movement, which is floating or sinking, it can reach a speed of 1.8mm per second under the tethered system with less mass about 0.055 kg and it can also reach a speed of 3.2mm per second with more mass about 0.23 kg. They also introduce the cost of transport (COT) to evaluate the performance between tethered system and non-tethered system, which indicated that non-tethered system could achieve a faster swimming speed at the same average input power 0.25W, voltage 7kV and frequency 0.2Hz. As shown in figure 4(b), the jellyfish-shaped non-tethered system can move up and down under the influence of voltage. Another application based on the jellyfish proposed by Keita et al [18]. They mainly focus on the movement of the horizontal plane,their under water robot is currently studied based on a tethered system and can finally reach 3.1 mm per second under the condition with 10kV and 4Hz, which is comparable with the former one. As shown in figure 4(c), the jellyfish robot can move from the right plane to the left under the influence of voltage. From the research above, we could easily find out that the cost of motion and the speed are the essential standard to evaluate the swimming robots. As shown in figure 4(d), this is one of the fastest-moving swimming robots during these years, which is proposed by Li Tie-fei et al. [19], their robot referred to the movement of Manta-ray. The soft structure is consist of the silicone body and the muscle laminates which is the combination of two dielectric elastomer and one hydrogel film, with the impact of the voltage, Maxwell stress forces the muscle laminates angles to bend and wave from 16.7 degrees to 26.9 degrees within 0.5T(one T represents a full flapping cycle), the swimming speed depends on the voltage amplitude, and it can maximize to 13.5cm per second with the condition at 10kV and 5Hz. Their soft fish can work properly in the range of 0.4 Celsius to 74.2 Celsius.

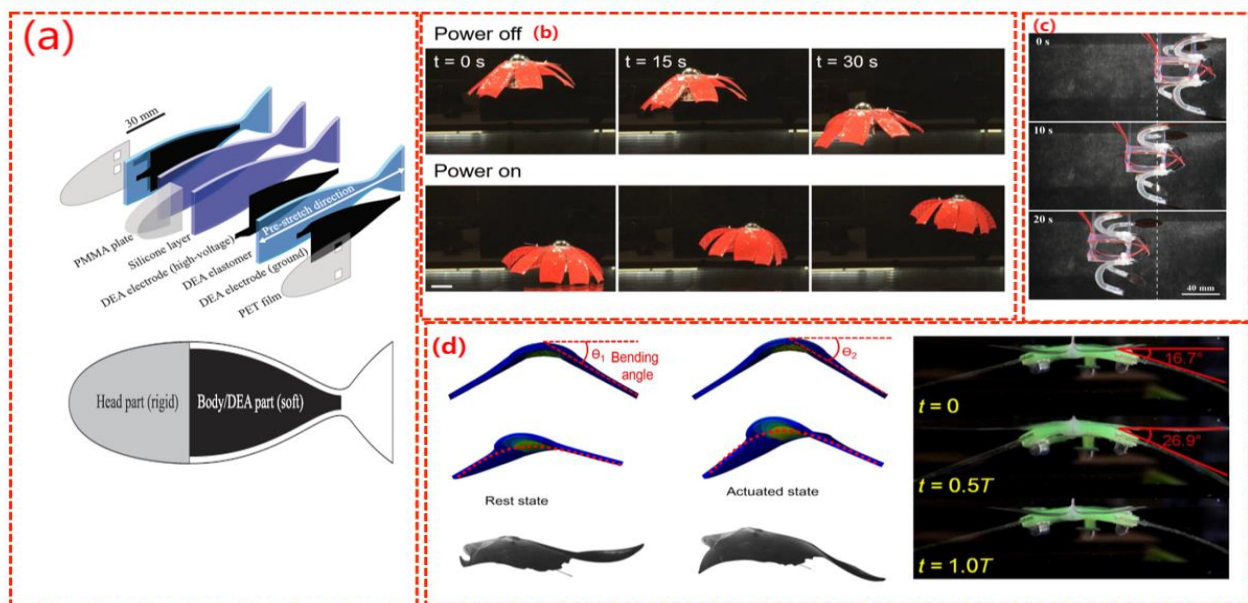


Figure 4. Dielectric elastomer based swimming robots (a)Fish-shape mixture with rigid DE robot. (Reprinted from [16], with permission). (b) Jellyfish DE based robot vertical movement. (Reprinted from [17], with permission). (c) Jellyfish DE based robot Horizontal movement. (Reprinted from [18], with permission) (d) Fast-moving Manta ray swimming robot. (Reprinted from [19], with permission).

2.4. Artificial muscles

Artificial muscles have always been a challenge during these years, dielectric elastomer has been proven a reliable material for soft robots. The artificial muscles could be directly applied to part of the core of human body. As shown in figure 5(a), Wang et al.[20] proposed a DE based artificial muscles combined with the plastic fibre, which are supposed to prevent the instability of the actuator,

two dielectric elastomer actuators were installed on the robot's skull to simulate the human jaw movement. Their studies are really helpful to develop humanoid-robot, especially for those robots designed for singing and speaking activities, their can finally achieve 48 percent of linear strains, which is quite similar to the natural human muscle. Another humanoid application is robot eye-balls proposed by Carpi et al. [21], as shown in figure 5(b), the eye-ball are allowed to move flexibly inside a robotic head, with lower cost of energy.

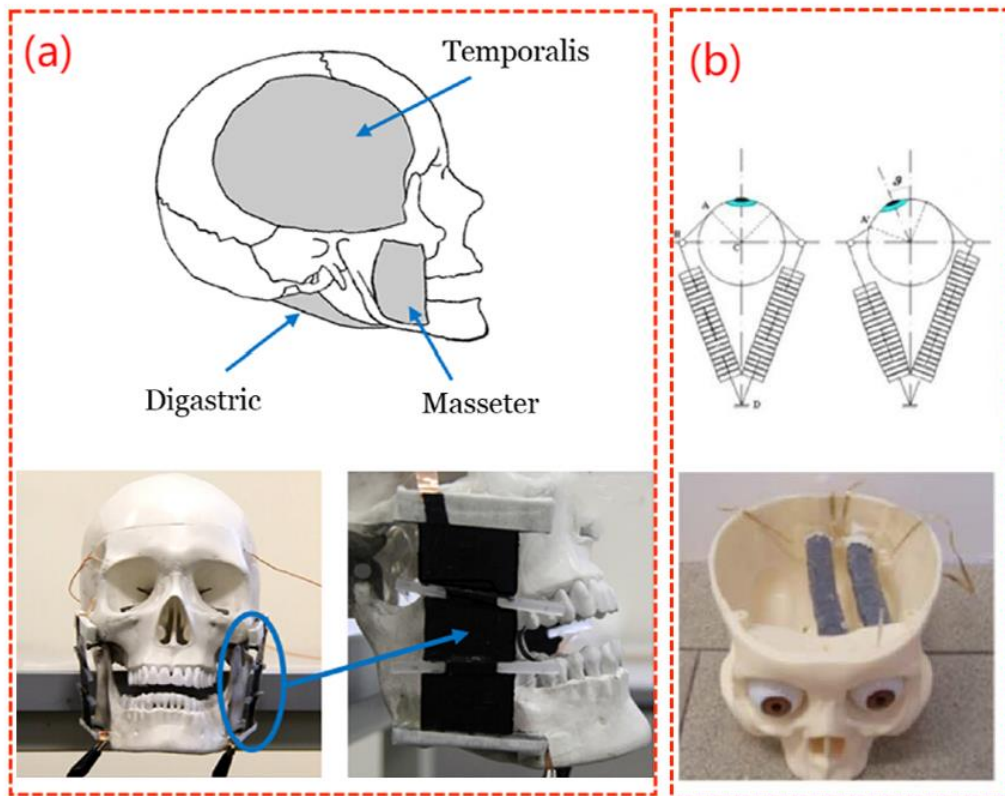


Figure 5. Dielectric elastomer based artificial muscles application. (a) Jaw movement based on the artificial muscles on a robotics skull. (Reprinted from [20], with permission). (b) Eyeballs movement simulation. (Reprinted from [21], with permission)

3. Conclusions

Although dielectric elastomer have been demonstrated in various applications for soft robotics, there still exist obstacles in putting these applications into use in the real world due to the limitation of dielectric elastomer. For DE-based grippers, they are expected to generate a greater force and grasp much bigger and heavier objects, the research mentioned above that multiple-DE layered gripper could solve this problem, but the improvement of output forces is not obvious through adding layers of the gripper, the cost of manufacturing and repair are high at the same time, so we still need to be in progress and find out more ways to provide better performance for the grippers. For ground robots and under water robots, moving speed and turning ability are commonly used to evaluate the capabilities of robots, however, this is not feasible if we ignore the cost of transportation and energy efficiency. When performing difficult tasks with robots, stability is far more crucial than speed, most the soft robotics systems are tested and developed and achieve their best performance under a tethered system, which indicate that soft robotics are weak while working under the non-tethered system. The biggest problem is that the characteristics of dielectric elastomer has determined that it would not be outstanding under a non-tethered system, the solution is to design an onboard system as shown in figure 4(d) or to mix rigid materials into the body structure, which means that such kind of soft robot are not completely soft. The design of On board system is also challenged due to the space inside the body structure, the hardware system including battery and sensors are difficult to assemble into the

robots, this problem is also relative to the load capability of soft robots, although dielectric elastomer has the advantage of less weight, it also indicates that such soft platform are not able to support any other computation devices except itself, in this case, the development of soft robotics will remain monotonous. In this paper, we introduced the common applications of DE based for soft robotics, and the challenges outlined remain the difficulties that more future work should be directed in upgrading the stability and durability, then the soft robotics would be brought to human daily life in the near future.

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