Biomimetic Soft Actuator: Design, Modeling, Control, and Applications

Hyouk Ryeol Choi, Member, IEEE, Kwangmok Jung, Sungmoo Ryew, Jae-Do Nam, Jaewook Jeon, Member, IEEE, Ja Choon Koo, Member, IEEE, and Kazuo Tanie, Fellow, IEEE

Abstract—A new biomimetic linear actuator named ANTagonistically driven Linear Actuator (ANTLA) that could be directly employed in both macro and microscale of robotic applications is introduced in the present work. The presented actuator provides cost effectiveness and simple fabrication process thanks to its plain construction. In addition to producing basic bidirectional rectilinear motions, the actuator is able to modulate its compliance that might be one of the critical elements of the actuator functionality for the biomimetic applications. For the test, the proposed actuator concept is fabricated and assembled in a microscale robot that generates annelid motion.

Index Terms—Actuator, artificial muscle, biomimetic, dielectric elastomer, electroactive polymer (EAP).

I. INTRODUCTION

RECENTLY, polymers are popularly considered as a substitute for the existing actuators. There are many different types of polymeric material that could be used for either actuator or sensors. One of the most promising materials might be electroactive polymer (EAP) of which ionic polymer metal composites (IPMC), conducting polymer, polymer gel, dielectric elastomer, and piezoelectric polymer are typical sort. In general EAPs are classified into two groups such as ionic and nonionic EAPs, depending on the basic physics of actuation [1], [2]. At present, actuator technology employing non-ionic EAP’s like dielectric elastomer or piezoelectric polymer are matured for the actual industry applications, although other polymers also have good potential to be implemented for practical use in the near future. Dielectric elastomers could be easily found at the moderate cost. For instance, polyurethane and silicone are typical examples of dielectric elastomers.

Although the basic actuation principle of the material is simple and straightforward, many different actuation concepts have been developed [3], [4], [6]–[10]. The stretched film type actuator is one of the most famous actuator configurations ever introduced. In addition the rolled, bow-tie shaped construction have been proposed by previous researchers [5].

In these configurations, the actuators deform by electric input but return to its original state by externally applied forces such as pretention. Thus, in a rigorous sense, they could not be regarded as a bidirectional actuation. Several features should be improved in order to be used for practical applications.

In the present work, an actuator made with single stretched elastomer film with bisectioned compliant electrodes is introduced. Each partition of the elastomer can provide “push-pull” type operation, and thus it can generate actively controlled bidirectional actuation. In addition, it enables to control actuator compliance that benefits biomimetic researches. Apparently bidirectional actuation and compliance controllability are the most important characteristics for the muscle-like actuator. The proposed design concept can easily satisfy these requirements without any mechanical power train. Since its fabrication process is very simple, it is obviously cost effective. Thanks to the structure simplicity, it can be applied to wide range of physical dimensions from micro-, to macroscale robotic applications. In this paper basic concepts and working principles of the proposed actuator are introduced. And modelling and analysis using closed form mathematical model of the proposed actuator is also delineated. Controlling position and modulating compliance are also demonstrated.

In addition, as a robotic application of the proposed actuator, a microrobot capable of mimicking the motion of the annelid is developed. Comparing with existing ones [11]–[20], the robot provides some advantages such as simple physics in actuation, softness, embedding actuators on a plastic frame, using no mechanical assembly component such as bolts and nuts. Especially, as noted in a few previous researches [21], the proposed approach can provide an innovative paradigm in design and manufacturing of robots. For example, a disposable robot which can be used just several times and do not need maintenance may appear in the future using the proposed polymeric material based technology.

II. PROPOSED IDEAS

The basic principles of actuation using dielectric elastomer is not willing to be mentioned in this paper, because it can be referred to the previous works [3]–[5].

The proposed actuator, called ANTagonistically-driven Linear Actuator (ANTLA), is based on the principle conceptually illustrated in Fig. 1. In the proposed design, the actuator is mainly composed of a prestretched elastomer film foiled on the frame, which is engaged with uniform pretension along the frame, which is engaged with uniform pretension along the