Artificial annelid robot driven by soft actuators

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Abstract
The annelid provides a biological solution of effective locomotion adaptable to a large variety of unstructured environmental conditions. The undulated locomotion of the segmented body in the annelid is characterized by the combination of individual motion of the muscles distributed along the body, which has been of keen interest in biomimetic investigation. In this paper, we present an annelid-like robot driven by soft actuators based on dielectric elastomer. To mimic the unique motion of the annelid, a novel actuation method employing dielectric elastomer is developed. By using the actuator, a three-degree-of-freedom actuator module is presented, which can provide up–down translational motion, and two rotational degree-of-freedom motion. The proposed actuation method provides advantageous features of reduction in size, fast response and ruggedness in operation. By serially connecting the actuator modules, a micro-robot mimicking the motion of the annelid is developed and its effectiveness is experimentally demonstrated.

(Some figures in this article are in colour only in the electronic version)

1. Introduction
Locomotion, which has been one of the most significant issues in robotics, becomes even important in advanced robotic applications, e.g. locomotion in unstructured environments. In dealing with the aforementioned problems, robotic researchers mainly concentrate on mimicking natures such as humans or animals recently. Typically, there are many reports on annelid-like robots, such as the inchworm or earthworm [1–5]. The annelid is one of the most popular mechanisms in robotic fields and it is employed in various areas such as in-pipe inspection robots, wall climbing robots, etc, because the locomotion of the annelid is the most simple and effective to move in arbitrary environments among the lower animals [6].

However, it is almost impossible to realize a robot capable of mimicking the biological locomotion of the annelid with existing technologies. For instance, traditional actuators such as electromagnetic motors, pneumatic actuators etc, do not meet the requirements as biomimetic actuators because their intrinsic properties are truly different from those of biological muscles. Shape memory alloy (SMA), often regarded as one of the candidates for artificial muscle, has been employed for a small sized annelid-like robot [1, 3, 4]. SMA may be adequate for the micro-robot because it has a simple actuation principle and structure. However, it should be noted that SMA actuators have low bandwidth and efficiency because of their working mechanism, i.e. heating and cooling. Among potential candidates, electroactive polymers (EAP) seem to have great potential to be a new means of actuation [7]. In spite of the technical difficulties their application areas are rapidly expanding especially in robotic fields since the actuation mechanism of the polymers is similar to the human muscle. Among the various kinds of EAPs, dielectric elastomers can be considered to be prospective because they are very soft and their deformation is much greater than that of any other existing one. The deformation of dielectric elastomers can be used in various ways to produce actuation [8–13]. The stretched film-type, the rolled and the bow tie actuators are