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Design and characterization of an actively deformable shell structure composed of interlinked active hinge segments driven by soft dielectric EAPs

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Abstract

Active shell structures with large out-of-plane displacement potential may be used to generate an interaction between the structural shape and the environment. Among the electroactive polymers (EAPs), in particular, the soft dielectric EAPs represent a promising technology to drive shell actuators due to their huge active strain potential and intrinsic compliance.

This paper presents a shell actuator based on soft dielectric EAPs, which can actively take complex, single-curved shapes. The actuator is composed of seven interlinked active hinge segments, where the pre-strained dielectric films are arranged in an agonist–antagonist configuration. The soft dielectric EAP films, which act as an active skin, are thereby mounted to a hinged mechanical backbone structure.

A computer-controlled system for the individual supply of the agonist–antagonist segments is proposed, where the DC high voltages provided by only one single HV amplifier is consecutively switched in a repeated loop to the active hinge segments.

The experimental characterization included, on the one hand, the quasi-static full angular displacement potential of the shell actuator. Angles of displacement exceeding 90° back and forth at the free end of the actuator were observed. On the other hand, we examined the dynamic behaviour of the shell actuator under phase-shifted sinusoidal activation of the hinge segments. As expected, the actuator displayed an "organic" propagation of transversal displacement waves along its principal axis (similar to the swimming motion of fish).

Keywords: Active structures; Electroactive polymers (EAPs); Soft dielectric EAPs; Shell actuator

1. Introduction

In recent years, soft dielectric EAPs have attracted much interest among the electroactive polymers (EAPs) due to their intrinsic compliance and outstanding active deformation potential [1–4]. Soft dielectric EAPs consist of a thin elastomer film, which is coated on both sides with compliant electrodes. When applying a DC high voltage to this compliant capacitor the electrodes squeeze the incompressible dielectric in its thickness direction, which thus expands in the plane (e.g. [1]).

So far, a multitude of promising types of dielectric elastomer (DE) actuators based on soft dielectric EAPs have been presented (e.g. [5,6]). Due to their unique properties, soft dielectric EAPs are seminal for lightweight active structures, where large deformations are needed. In particular, this actuator technology is promising for active shell structures, which may accomplish "organic" shape changes. Active shells in the micro- or macro-scale may be utilized to generate interactions between the surface of a structure and its environment. Potential applications include

- Drag and/or oscillation reduction on wind-exposed structures (e.g. buildings, bridges).
- Fish-like propulsion of objects through fluids (Fig. 1).
- Reflection/absorption of electromagnetic waves (e.g. adaptive mirror [7], flexible parabolic reflector).

In this study we propose a macro-scale shell actuator based on the agonist–antagonist configuration inspired by nature

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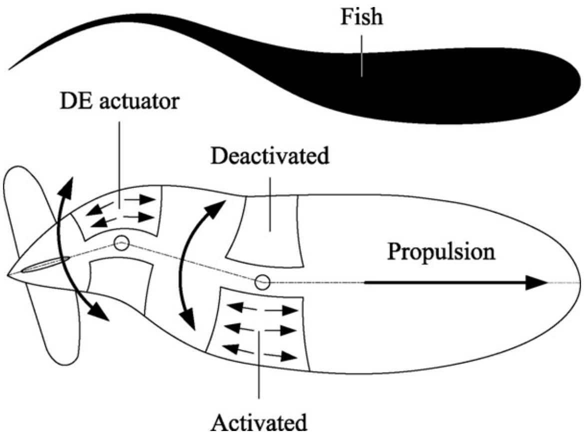

Fig. 1. Inspired by the continuous shape changes of fish for locomotion (top) a fish-like propulsion for blimps based on EAPs (bottom) was proposed [8].

(Section 2). This EAP actuator consists of seven interlinked agonist–antagonist segments (Section 3), which can be independently activated by an appropriate control/supply system (Section 4). The resulting shell actuator is experimentally characterized in terms of its active shape change potential (Section 5).

2. Conceptual approach

2.1. Basic considerations

For simplification we assume that the shell actuator is composed of an array of identical active segments (Fig. 2, left). In order to accomplish quasi-continuous out-of-plane displacements (displacements into the z direction), the shell actuator requires high spatial resolution in active segments. In addition, all segments need to be supplied/controlled independently.

When focusing on active shell structures, which can take complex, single-curved shapes (Fig. 2, right), the corresponding active segments need to be capable to execute uniaxial bending (bending around the y axis).

2.2. Agonist–antagonist configuration

For its application to DE actuators, the widely used acrylic film VHB 4910 (supplied by 3 M) is strongly pre-strained in its planar directions to reduce the required activation voltage level [1]. In order to maintain the DE film in this biaxially pre-strained state, a support structure is needed. This support structure must offer the mechanical degrees of freedom (DOF) to enable the desired shape changes of the active structure. Hence, the support structure of each active segment of a uniaxial bending shell actuator has to provide a single rotational DOF. The segments' angular displacement is actively controlled by soft dielectric EAPs. Note that the shape change of the proposed shell structure is thus not based on classical bending but on an actively controlled, rotational displacement of the support structure.

Inspired by the structure of biological agonist–antagonist systems, where two opposing muscles are fixed at jointed bones (e.g. human arm, Fig. 3, left), a similar configuration was proposed for the active hinge segment based on soft dielectric EAPs [9]. Two DE film stacks pre-strain each other (pre-stretch ratios $\lambda_x^{(i)} \times \lambda_y^{(i)}$ in the directions x and y) via a hinged support structure with length L, height H and a hinge bearing positioned at a distance of L_P from the left (Fig. 3, centre).

Under active expansion of one of the pre-strained DE film stacks at a time, the support structure executes an angular displacement to $\pm\varphi$ (Fig. 3, right). Note that the directions of motion of the arm and the DE configuration are opposite to each other since a biological muscle contracts under activation, while a DE actuator expands.

The performance of the agonist–antagonist segment was optimized based on quasi-static modelling to achieve large angles of displacement as well as large blocking moments by adjustment of the structural design of the support structure and the setup of the DE actuators [9]:

- *Design of the support structure*: Although better performance would result from the central position of the hinge bearing ($(L_P/L) = 0.5$) its lateral position ($(L_P/L) = 0$) was preferred in

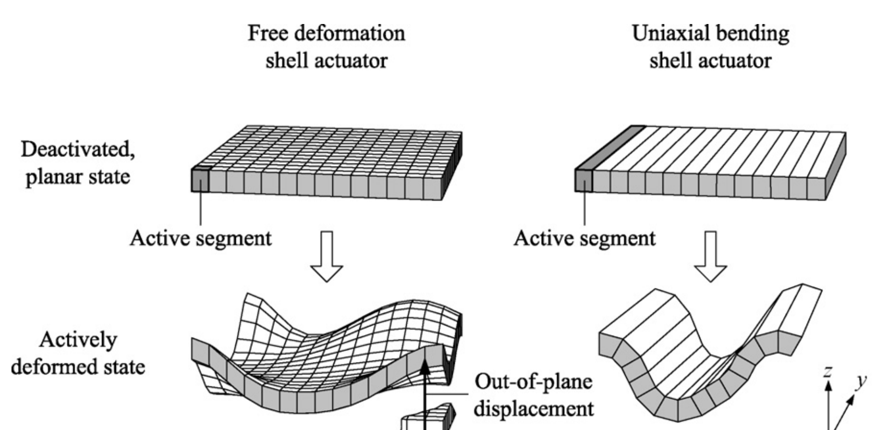

Fig. 2. The active shell structure is assumed to be composed of an arrangement of active segments. According to the active deformation potential of the active segments the shell structure can either accomplish free out-of-plane displacements (left) or simply uniaxially bend (right).