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Towards a closed loop soft fishtail actuator – Soft sensors utilized for measurement of soft fin curvature

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1 Introduction

Biorobotics as an emerging field can facilitate hypothesis testing in animal locomotion. Soft robotics in particular has potential to provide physical models of animals with heterogenous tissue characteristics that have material properties of varying stiffness. Although most robotic fish developed to date consist of rigid components [1], soft active materials as pioneered by Suzumori and colleagues can be used to emulate animal locomotion [2].

Here, we propose that integration of soft sensors can help decipher how animals move by facilitating studies on the neuromechanics of locomotion. Undulatory body-caudal-fin movement of the body is the most important mode of locomotion in fishes, and numerous studies of body kinematics and muscle activity patterns have provided insights into the mechanics of swimming. How key parameters such as the extent of bilateral muscle activation affect propulsive performance is under-explored due to the difficulty to experimentally manipulate muscle activation in live, freely swimming fishes. To gain insight into undulatory locomotion and mechanisms for body stiffness control, we manufactured a set of actively controlled pneumatic actuators [3] attached to a flexible foil in a companion study [4].

We measured thrust production by the soft robotic fish-like physical model at cyclic undulation frequencies ranging from 0.3Hz to 1.2Hz in a recirculating flow tank at flow speeds up to 28cm/s. We found the system generated considerable thrust and self-propelled speed was approximately 13cm/s or circa 0.8 foil lengths per second or circa when actuated at 0.55Hz. When we changed the extent of bilateral co-contraction in a range from -22% to 17% of the cycle period we found that thrust was maximized with some amount of simultaneous left-right actuation of approximately 3% to 6% of the cycle period [4]. Here, we seek to close the loop by measuring bending on the fish body itself with the goal to explore how amplitude control can be used to modify axial body stiffness and affect swimming performance.

2 Materials and Methods

Two soft actuators were attached on each side of a flexible panel with stiffness comparable to that of a fish body. For device control and operation we designed the soft robotic fish (Fig. 1. A) such that we placed several components off-board, such as the microcontroller circuit board (Arduino, Nano, SmartProjects, Italy), pressure regulator and solenoid valves (Parker V2 Miniature Pneumatic Solenoid Valve), the pressure sensor (BSP B010-EV002-A00A0B-S4, Balluff Inc, Florence, KY 41042).

In order to generate the desired undulatory motion patterns we used Pulse-width modulation control for control of phasing for actuator pressurization. We pressurized the system using compressed air ranging from 0.4 bar to 1.5 bar (40 kPa to 150 kPa, respectively).

Soft sensors were manufactured using 3D-printed molds as described in [5, 6]. Two layers of a hyperelastic elastomeric materials were bonded together. One of the layers contains microchannels in which a liquid metal (eutectic Gallium Indium, or eGaIn) is injected. When the fin is curved under the effect of the soft actuators, strain is

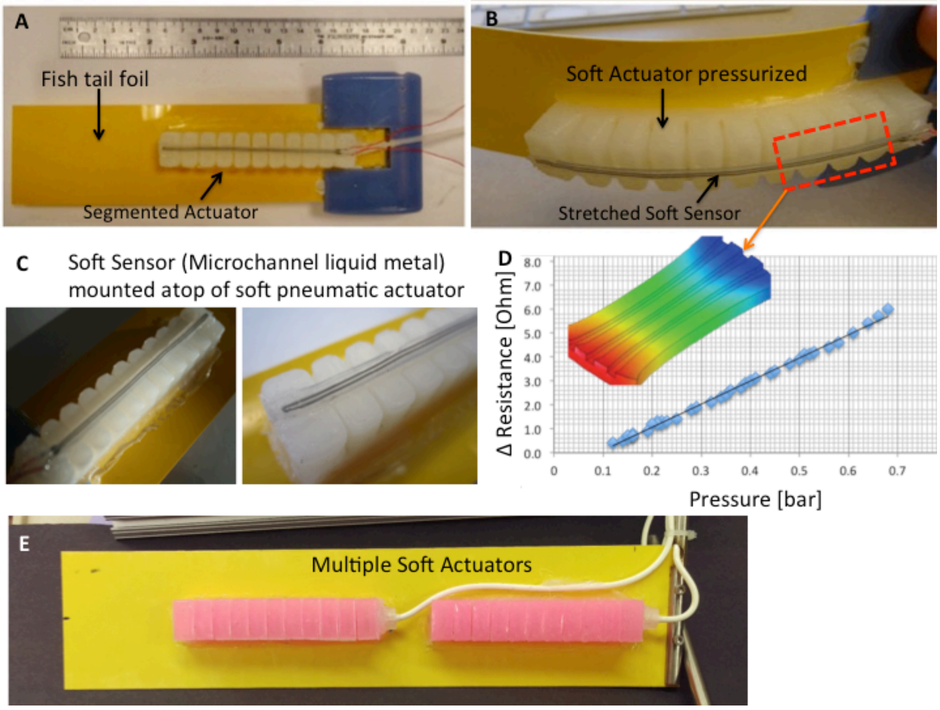

Figure 1: Soft Robotic Fish (A) in pressurized state (B). Soft actuators and soft sensor (C). Plot and shows resistance over time (D). Inset shows strain on soft elastomeric material. For body-caudal fin swimming control multiple actuators are added (E).

applied to the soft sensors, which will increase the overall length of the eGaIn microchannels (Fig. 1 B, D), thus increase the electrical resistance. The information on the fin's curvature can then be correlated from the resistance measurement. The change in resistance in response to bending was measured using a multimeter.

3 Results and Discussion

Having found that the active pneumatic fish-like physical model is capable of producing substantial trailing edge amplitudes with a maximum excursion equivalent to 1.4 foil lengths, and of generating considerable thrust, we are now developing the capability of sensing curvature in order to achieve amplitude control.

We tested a soft sensor mounted on top of the soft pneumatic actuator [Fig 1 A, C]. We found that a sensor with microchannels containing liquid metal was capable of operating when submerged under water. The water pressure did not appear to aversely affect the sensor measurement capability. The sensor allowed for measurement of strain changes as the fish body as it was bending. When the soft pneumatic actuator was pressurized, we observed that this resulted in greater fin curvature as shown in Fig. 1B. This change in curvature resulted in the soft sensor being stretched (Fig. 1D). As a result we measured a change in the electrical resistance in the liquid metal contained in the microchannel. We found that the resistance increased proportionally the more the actuator was bent when pressurized.

Having tested the feasibility of using the soft sensor for undulatory swimming in still water, the next step is closing the loop for tests at several water flow speeds in the recirculating flow tank. The added capability of curvature information permits to close the loop thus enabling the measurement of different curvatures on the fish body at different water flow values while keeping same pressurization of the actuator constant. This facilitates the control of the fin's displacement amplitude.

At this point, the sensor gives us valuable information on curvature in a static water flow configuration. The next step consists of utilizing this information when water is flowing. This added capability will allow for applying the necessary pressure correction to remain at the desired curvature, independently of the instantaneous water flow speed.

In this spirit, the experimental platform developed here provides a new physical model for studying aquatic propulsion with active control of undulatory kinematics. Moreover, the addition of multiple sets of actuators in series in the quad setup (Fig. 1 E) will provide better control of body and tail undulations. Body-caudal fin shape changes facilitated by soft actuators could enhance maneuverability in rapid turning responses in future robotic fish.

3 References

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