Bio-inspired Jellyfish Robots based on Ionic-type Artificial Muscles

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Abstract: As 3D printing technology and soft polymer manufacturing systems have been developing rapidly, soft robots become a hot issue as practically engineered systems. More specifically, electro-active artificial muscles have been considered as a strong candidate to be a biomimetic locomotive actuator in soft robots. In this study, ionic polymer-metal composite actuators were used to fabricate a bio-inspired jelly fish robot with a realistic pulse and recovery actuation mode. The vertical floating motions of the bio-inspired jellyfish robot under various input signals were carefully investigated. Present results indicate that the bio-inspired electrical input signal with pulse-recovery process can induce much higher locomotive velocity of the bio-inspired jellyfish robot in comparison with pure sinusoidal excitations.

Key-Words: biomimetic, fish robot, ionic polymer-metal composite, actuator, artificial muscle, locomotion

1 Introduction

Jellyfish is one of the most awesome marine animals that swim spectacularly like a psychedelic dance under water. Biologically jellyfish are of the phylum Cnidaria, a simple marine group of both fixed and mobile animals. While sea anemones, sea whips, corals and hydroids are polyps that grow attached to rocks, jellyfish and colonial siphonophores, like the Portuguese man-of-war, are either actively swimming or subject to flows and currents. The inherent property of both types of life history is the radial symmetry of body parts that radiate from a central axis. This symmetry allows jellyfish to detect and respond to food or danger from any direction. Most jellyfish are semitransparent or glassy and bell-shaped, measuring from less than an inch to more than a foot across the bell; some may reach seven feet in diameter.[1]

Ionic polymer metal composites (IPMCs) provide space-saving bio-mimetic actuation owing to their key advantages including comparatively large stroke, quick response, power efficiency, light weight, flexibility, facile processability, steering controllability, and noiseless locomotion. Furthermore, IPMCs have been applied to artificial muscles, actuator/sensor integrated systems, and biomimetic robots.

In this study, a biomimetic jellyfish robot based on IPMC actuators was fabricated and activated to mimic real locomotive behavior. In many previous studies on biomimetic robots that used IPMC actuators, flat IPMC actuators were used. To mimic the shape of jellyfish with a complicated external form, curved IPMC actuators were fabricated by the use of thermal treatments with a fixing mold.[2-4] Also, to get an efficient thrust force, the electric input signal was generated following the real locomotion of jellyfish. The living jellyfish has two-phase motions in its cycle: a fast-pulse phase and a slow-recovery phase.[5] The floating velocity of the jellyfish robot under bio-inspired input signals were measured and compared with those under simple harmonic input signals.

2 Experimental and results

2.1 Fabrication of the jellyfish robot

A bio-inspired jellyfish robot with curved IPMC actuators was developed for mimicking the real locomotion of jellyfish with recovery and pulse phases as shown in Fig. 1 a. The curved IPMCs, which are used for the legs of the jellyfish robot, were developed through thermal treatment, resulting in obtaining a bell-shaped IPMCs with constant curvature. Additionally, to prevent leakage of water and loss of thrust force in the pulse process of jellyfish robot, cellophane skirt was bonded onto curved IPMC legs via a line-type adhesive tape as shown in fig 1. b and c.

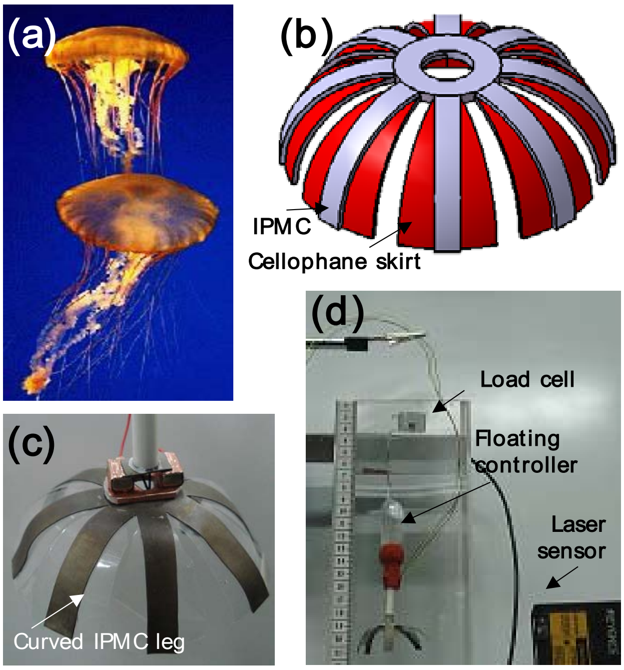

Fig. 1 Bio-inspired jellyfish robot; (a) jellyfish and its locomotion, (b) final prototype of the jellyfish robot, (c) jellyfish robot with curved IPMC legs, (d) experimental set-up.

2.2 Bio-inspired input signal

The bell diameter and the buoyancy of the bio-inspired jellyfish robot under various actuation signal were measured using two laser sensors (OFV 303 and LK-031) and a strain-gauge load cell (LVS-5GA) in real-time, as shown in Fig. 1 d. And the bio-inspired input signal for efficiently actuating the jellyfish robot consists of a periodic signal with two-phase locomotion, i.e. fast pulse and slow recovery phases as shown in Fig. 2. These phases are the real locomotion of a living jellyfish and defined via the size changes of the bell diameter of the jellyfish. Fig. 3 exhibits that the bio-inspired jellyfish robot can mimic the two-phase locomotion of real jellyfish (left figures of Fig. 3.) via the proposed bio-inspired electrical signal-driven the biomimetic locomotion of jellyfish robot. To validate quantitatively the efficiency of the pulse and recovery phases in locomotion, a simple harmonic input signal was additionally used to compare the floating displacement and velocity of the jellyfish robot. For performance comparison, the equivalent RMS (root-mean-square) value of two different signals was used. The bio-inspired input signal with the amplitude of 3 volts and the sinusoidal signal with equivalent RMS value of the amplitude of 3.306 volts during one cycle were applied as shown in Fig. 2.

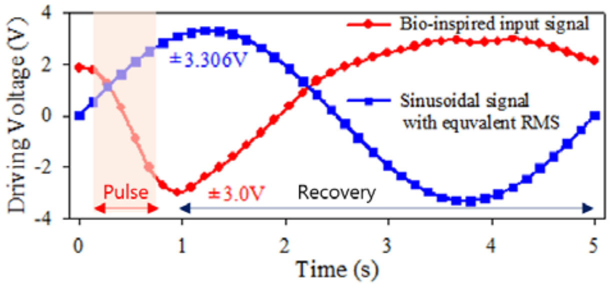

Fig. 2 Bio-inspired input signal considering variation of the bell diameter of the jellyfish robot.

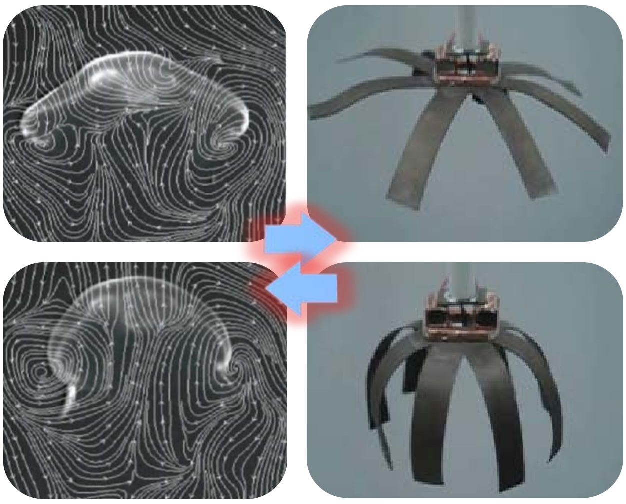

Fig. 3 Two-phase locomotion of real jellyfish and bio-inspired jellyfish robots.[2, 6]

2.3 Floating displacement

Floating displacements under the bio-inspired input signals and sinusoidal input signals with excitation frequencies of 0.2, 0.5, 1.0, 2.0 and 10.0 Hz were measured as shown in Fig. 4. The variation values of floating displacement for 5 cycles were calculated. Under the bio-inspired input signal, the jellyfish robots floated significantly upward at all excitation frequencies. On the other hand, the jellyfish robot did not float upward when the sinusoidal input signals were applied. The total floating displacement reached a peak of 1.93mm under the bio-inspired input signal of ± 3.0 V peaks at 0.1 Hz frequency, as shown in Fig. 4. Therefore, the bio-inspired input signal shows better actuation efficiency in comparison with a simple harmonic signal with respect to the vertical floating displacement and velocity.

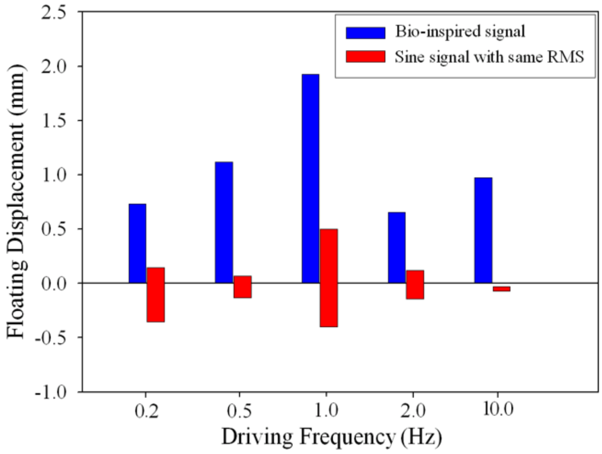

Fig. 4 Maximum floating displacement during 5 cycles.

2.4 Frequency response and floating velocity

The frequency response function of an IPMC leg was measured to ascertain the natural frequency of the jellyfish leg and to compare the response levels as the excitation frequency was varied. The natural frequency is very important because it can generate a large displacement with a relatively low energy. Therefore, the resonance-frequency excitation will cause large oscillatory deformations of the IPMC actuator, thereby resulting in large floating displacement and velocity. To obtain the frequency response function of an IPMC leg, a sine-swept method was used with an NI-PXI system and the LabVIEW program. The excitation of the IPMC leg was done under water with an electrical input to the IPMC leg. The response of the IPMC leg was measured with the laser-displacement sensor, which was installed vertically (Fig. 1 d). There are two points which shows a high floating velocity compared with the circumstance frequency. One is near 1.2Hz, and the other is near 2.0 to 2.2Hz. The floating velocity is fastest at 1.2Hz because of the operation frequency of the jellyfish robot. The average first natural frequency of eight IPMC legs was about 2.37 Hz and the average second natural frequency was about 16.60 Hz as shown in inset of Fig. 5. Since the IPMC actuators show transverse large displacements under low-frequency excitations below 10 Hz, the first natural frequency of 2.2 Hz will be advantageous for getting higher floating displacement and velocity as shown in Fig. 5.

4 Conclusion

In this study, a bio-inspired jellyfish robot that is based on curved IPMC actuators with a curved initial deformation was fabricated and activated for mimicking the real locomotion of jellyfish with pulse and recovery processes. To imitate the curved shape of the jellyfish, a thermal treatment was applied to obtain a permanent initial deformation of a hemispherical form during manufacturing process of IPMC actuator. A bio-inspired input signal was generated for mimicking the real locomotion of the jellyfish with two-phase locomotion of pulse-recovery processes. The floating displacement and velocity of the biomimetic jellyfish robot under various input signals were measured and compared. As a result, the bio-inspired input signal that mimics the real locomotion of jellyfish induced much larger changes in the vertical floating displacement and velocity of the biomimetic jellyfish robot in comparison with sinusoidal input signal. Although certain problems are still to be resolved in the power system and in buoyancy control, the newly developed IPMC actuators with a constant curvature through thermal treatments may possibly be promising candidates that can be successfully applied to biomimetic robots with arbitrary surface curvatures.

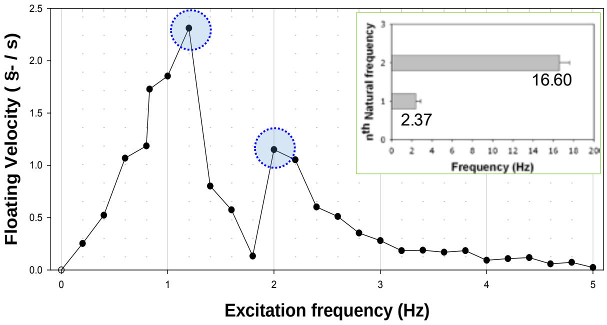

Fig. 5 Floating velocity of the jellyfish robot with the excitation frequency (inset: n^th natural frequency of IPMC legs).

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