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Editorial

Bio-Inspired Smart Machines: Structure, Mechanisms and Applications

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With the long-term evolution of nature, each creature has its unique structure and function, which can adjust to unstructured environments with diversity. These structures, mechanisms, and potential principles from biology will definitely excite new ideas for improving and optimizing conventional machine designs and control. By imitating certain characteristics of these creatures, such as grasp, twist, locomotion, or flying, etc., bio-inspired smart machines can engage in certain difficult tasks instead of human beings, such as medical surgery, rapid manufacture and assembly, disaster search and rescue, and scientific investigation. Therefore, bio-inspired smart machines have an important research significance and broad developmental prospects.

In light of this, this Special Issue provides an international forum for professionals, academics, and researchers to address some of the latest theoretical and technological advances in bio-inspired smart machines and their structure, mechanisms, and applications. After a stringent peer review process, eighteen papers were finally included in this Special Issue, which cover the following aspects: (1) bio-inspired machines and robotics, (2) bio-inspired modeling and control, and (3) bio-inspired sensors and active materials. A summary of the accepted papers is outlined below.

In the context of bio-inspired machines and robotics, a weevil-inspired jumping mechanism was designed in [1]. In this paper, a miniature prototype was designed to reproduce a weevil's jumping mechanism with its working principle and anatomical structure to verify how weevils' jumping mechanisms work; it performed well in terms of its jumping height. This paper presented the anatomical structure and working principle of the weevil jumping mechanism, followed by an explanation and analysis of its kinematics and dynamics, then performing virtual prototype simulations to compare different design schemes, with results guiding the parameter optimization and subjecting a prototype machine into a height test. In comparisons among the existing jumping mechanisms whose jumping method is bio-inspired, the present design weighs 44.7 g and can jump to a maximum height of 2 m.

To meet the requirements for the flexible end-effectors of industrial grippers and climbing robots, inspired by the animal attachment mechanism, a bio-inspired adhesive unit (Bio-AU) was designed in the second study [2]. Based on the lamination mold casting process, the "simultaneous molding and assembly" method was established, which can be applied to form and assemble complex cavity parts simultaneously. Moreover, the dovetail tenon-and-mortise parting structures were analyzed and designed. Furthermore, the adhesion between the parting surfaces can be improved using plasma surface treatment technology. By applying the above methods, the assembly accuracy and pressure-bearing capability of the complex flexible cavities are improved, which reduces the individual differences between the finished products.

In [3], the authors proposed two new flexible perching grasping mechanisms inspired by a bird's claw, one of which is articulated and the other is resilient. The difference being that the former has a pin-articulated claw structure and uses a double fishing line to perform the grasping and resetting action, while the latter uses a resilient linking piece, a single fishing line, and a resilient linking piece to perform the grasping and resetting action. The results of the experiments show that the two types of perch gripping mechanism have their own advantages and disadvantages. Another work, [4], was also inspired by birds, which proposed and fabricated a single-joint worm-like robot with a centimeter scale, the motion of which can be easily guided by a magnet. The robot consists of a pneumatic deformable bellow and a permanent magnet fixed in the bellow's head that will generate magnetic force and friction. The experiment exhibits its excellent environmental adaptability. Moreover, the robot's motion was successfully guided under the presence of the magnetic field, which shows a great potential for pipeline detection applications.

In [5], a four-track twin-rocker bionic rescue robot with an inner and outer concentric shaft was designed to achieve the best obstacle surmounting performance of a mobile robot in the rescue environment. From the viewpoint of dynamics, the motion process of the mass center of the robot when climbing steps forward and backward was studied. The maximum obstacle height of the robot was calculated. The relationship between the elevation angle of the car body, the swing angle of the rocker arm, and the height of the steps was analyzed using a simulation. The simulation results show that the maximum forward and reverse obstacle crossing heights were 92.99 mm and 155.82 mm, respectively.

A tubular stiffening segment based on layer jamming was proposed in [6], which can temporarily increase the stiffness of the soft robot in the desired configuration. First, the authors provided the details of the TSCR design, including the mechanical design and bio-inspired compliant spine mechanisms. Then, an analytical model of a two-layer jamming structure was proposed, as well as extending predictions to many-layer jamming structures. Experimental tests show that the bending stiffness of the initial TSCR increased by more than 15$\times$ at 0°, 30$\times$ at 90°, and 60$\times$ in compressive stiffness.

In [7], the effect of exoskeleton assistance on preferred speeds was tested. The U-shaped oxygen consumption and lower limb muscle activity curve with the minimum at preferred frequency were obtained by inviting participants to participate in the test, which indicated that the resonant condition existed under the preferred condition. Average metabolic reductions of 4.53% and 7.65% were found in the preferred condition compared to the general and comparison condition, respectively.

In [8], with the aim to improve the mobility and adaptability of WCR to complex urban operating environments and expand the application scope of the robot according to the clinging characteristics of different creatures, a double propeller wall-climbing robot (DP-Climb WCR) with a hybrid adhesion system was designed that can be internally transitioned based on the principle of a biomimetic design from the perspective of robot dynamics. Through mechanical and aerodynamic experiments, it was verified that the robot's actual output pulling force can meet the transition motion demand, and the robustness and adaptability of the WCR to complex application environments are improved.

In [9], a six-wheeled wire-rope-climbing robot was proposed. Under the condition of its own weight of 3.8 kg, the robot can carry a maximum of 8 kg of working tools for online laser cleaning and the maintenance of steel wire ropes and a visual safety inspection. The developed climbing robot is composed of separable driving and driven trolleys. It adopts the spring clamping mechanism and the wheeled movement method and can also easily adapt to the narrow working environment and the different diameter ranges of the sluice wire rope.

Within the context of bio-inspired modeling and control, a novel process parameter optimization approach for laser cladding is proposed in [10], based on a multi-objective slime mold algorithm (MOSMA) and support vector regression (SVR). In particular, SVR is used as a bridge between target and process parameters for solving the problem of lacking accurate information regarding the function relationship. The performance of the proposed approach was evaluated using the TOPSIS method, based on actual laser cladding data, and was compared with several well-known approaches. The results indicate that the optimal process parameters obtained by the proposed approach have a better process performance.

In [11], a bio-inspired compound continuum robot (CCR) combining the concentric tube continuum robot (CTR) and the notched continuum robot was proposed to design a high-dexterity minimally invasive surgical instrument. A kinematic model, considering the stability of the CTR part, was established. The unstable operation of the CCR is avoided. The simulation of the workspace shows that the introduction of the notched continuum robot expands the workspace of the CTR. The dexterity indexes of the robots are also proposed, and the simulation shows that the dexterity of the CCR is 1.472 times that of the CTR.

In [12], an improved ANCF lower-order plate element was used to increase the accuracy of the Yeoh model and characterize the geometrical structure of silicone rubber fingers, taking into particular consideration the effect of volume locks and multi-body system constraints. First, the improved Yeoh model based on the ANCF plate element is introduced; then, on the basis of the above-mentioned theory, the computation of a silicone rubber finger is presented. The simulation results showed that the motion performance of the flexible finger can be characterized by the proposed model effectively, including the expansion, deformation, bending status, and so on, under different air pressures.

In order to analyze the effect of higher-order harmonics on the hub load, a rotor that can realize individual blade pitch control was designed in [13]. The Glauert inflow model was introduced to calculate the induced velocity of rotor blades in a rotor disk plane, and the Leishman Beddoes (L-B) unsteady dynamic model was employed to calculate the aerodynamic forces of each section of a rotor blade. The results showed that the influence of each high-order harmonic control on the reduction in the individual blade vibration load is similar in different advanced ratios.

In [14], an impact load identification method based on impulse response theory (IRT) and a BP (back propagation) neural network is proposed. By extracting the peak value in the rising oscillation period of response, it transformed the excitation and response signals into the same length. First, it is deduced that there is an approximate linear relationship between the discrete time integral of the impact load and the amplitude of the oscillation period of the response. Second, a BP neural network was used to establish a linear relationship between the discrete time integral of the impact load and the peak value in the rising oscillation period of the response. Third, the network was trained and verified. The results show that this method has a high accuracy and application potential.

In [15], a control system for desktop experimental manipulators based on an audio-visual information fusion algorithm was designed. The robot could replace the operator to complete some tedious and dangerous experimental work by teaching it the arm movement skills. The system is divided into two parts: skill acquisition and movement control. For the former, the visual signal was obtained through two algorithms of motion detection, which were realized by an improved two-stream convolutional network. The latter employed motor control and grasping pose recognition, which achieved precise controlling and grasping.

In the process of trajectory tracking using the linear quadratic regulator (LQR) for driverless wheeled tractors, a weighting matrix optimization method based on an improved quantum genetic algorithm (IQGA) was proposed in [16] to solve the problem of weight selection. A kinematic model of the wheel tractor was built based on the Ackermann steering model, the state weighting matrix in the LQR controller was optimized using IQGA, and, finally, a joint simulation was performed using Carsim and MATLAB. The simulation results after comparing the other four optimization algorithms showed that the proposed IQGA speeds up the algorithm's convergence, increases the population's diversity, improves the global search ability, preserves the excellent information of the population, and has substantial advantages over other algorithms in terms of performance.

As to the context of bio-inspired sensors and active materials, a new strategy was proposed for developing electronic skin with tactile sensing and pain warning in [17]. A bionic artificial receptor with innocuous sensing and damage warning functions based on the coordination of the ion–electric response principle and mechanical signal attenuation was fabricated. The ion-sensing film provides the carrier of touch or pain perception, while the PDMS layer as a soft substrate is used to regulate the perception ability of the receptor. The sensing voltage of the artificial receptor primarily derives from the bending deformation of two IPMC sensory layers. Experiments show that the sensitivity of the touch response and pain response is 0.136 mV/Pa and 0.026 mV/Pa, respectively. Additionally, the distinction ability of touch and pain becomes more pronounced under a higher elastic modulus and larger thickness.

To obtain the lattice structure with an excellent energy absorption performance, the structure of a loofah inner fiber was studied by [18] to develop the bionic design of the lattice structure by an experiment and simulation analysis method. From the compression experiment of the four bionic multi-cell lattice structures (bio-45, bio-60, bio-75, and bio-90) and VC lattice structures, its shown that all are made of PLA and fabricated by the fused deposition modeling (FDM) 3D printer. The comprehensive performance of the bio-90 lattice structure is the best in the performance of the specific volume energy absorption (SEAv), the effective energy absorption (EA), and the specific energy absorption (SEA). Based on the experimental result, the energy absorption performance of the bio-90 lattice structure was then studied using a simulation analysis of influence on multiple parameters, such as the number of cells, the relative density, the impact velocity, and the material.

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