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Gecko-inspired robot with body-height adaptability

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1 Introduction

The gecko is the largest animal that can utilize its adhesive feet for versatile locomotion. Therefore, the gecko has been used as a bio-inspired model for creating new solutions for robot locomotion. These solutions include bio-inspired adhesive materials, robot structure design, and locomotion control mechanisms for gecko-inspired robots with high performance [1]. For example, Kim et al. [2] developed a gecko-inspired robot with link bar structures, which can climb on vertical walls with different types of surfaces. Murphy et al. [3] developed a wheel leg climbing robot, which can realize omnidirectional wall climbing and even transition from the ground to wall. Seo et al. [4] developed a climbing robot with a four-bar mechanism, which can adapt to various curvatures. The common features of these gecko-inspired robots are their lightweight, simple structure and actuator system, and the classical control method, which impart these robots with effective abilities and enable convenient engineering. However, gecko-inspired robots do not possess all the locomotion features of actual geckos, such as the ability to traverse the nonstructural or obstacle terrain.

To surpass the locomotion limit of gecko-inspired robots, and to understand the locomotive skills of geckos, traits to those of geckos should be imparted to gecko-inspired robots. Our work begins with an analysis of the skeletal system of the gecko to design a similar structure for a gecko-inspired robot (Fig. 1). We analyse the kinematics of gecko, to determine the principles for building the biomechanical structure of a gecko-inspired robot (Fig. 1(a)). We investigate the adhesive feet of a gecko to design a hybrid soft-rigid foot for the gecko-inspired robot (Fig. 1(b)). After the manufacturing of the gecko-inspired robot (Fig. 1 and 2(a)), a central pattern generator (CPG) with a radial basis function (RBF) neural network [5] (Fig. 2(a)) was applied to control it. The aforementioned combination of the biomechanical structure, hybrid feet, and CPG-RBF-based control is used to mimic the complex locomotion behavior of geckos. Finally, experiments were conducted to test the performance of the developed gecko-inspired robot. The results (Fig. 2(b)) show that the gecko-inspired robot can overcome obstacles using its body-height adaptability.

2 Methods

2.1 Biomechanical leg of the gecko-inspired robot

The skeletal system of the gecko is shown in Fig. 1(a); the circles with different colors mark the locations of active joints; the blue circle indicates the shoulder or hip, the green circle indicates the elbow or knee, and the orange circle indicates the wrist or ankle. Based on the analysis of the kinematics of the gecko, the biomechanical leg structure with four active and three passive degrees of freedom was incorporated into our gecko-inspired robot, as shown in Fig. 1(a). The shoulder of the gecko-inspired robot is composed of joint 1, joint 2, and joint 3. Joint 4 is present on the robot's elbow, and the wrist is a ball joint with three passive degrees of freedom, which connects the forelimb and foot.

2.2 Hybrid soft-rigid adhesive foot

Fig. 1(b) shows the adhesive foot of the gecko and gecko-inspired robot. The gecko's foot can be divided into three parts according to its different functions [6]. The rigid part is called the arcuate penultimate phalanx, which can control the movement of the toes accurately. The soft part comprises a long flexor tendon, the reticular network, and the sinus, which can provide buffering when the foot collides with the walking surface. The bottom layer is lamella [7], which provides the adhesive force when the gecko attaches to a surface. The foot of the robot was designed as a sandwich structure according to the analysis of the gecko's foot. It consists of an upper rigid alloy pad, a middle soft rubber buffer, and a bottom dry adhesive material [8].

2.3 Locomotion strategy

The locomotion strategy of the gecko is different from that of other animals because of the adhesive property of the gecko's feet. We analysed the stance phase of the gecko's movement, which was recorded using a high-speed camera. Three periods are distinctly observable shown in Fig. 1(c). In the attaching period, the gecko starts to gradually roll its toes onto the surface. In the holding period, the gecko pushes its body forward by pulling the limb backwards. In the detaching period, the gecko tears the bottom adhesive material from heel to tip. The locomotion strategy based on this concept was used in our gecko-inspired robot. From

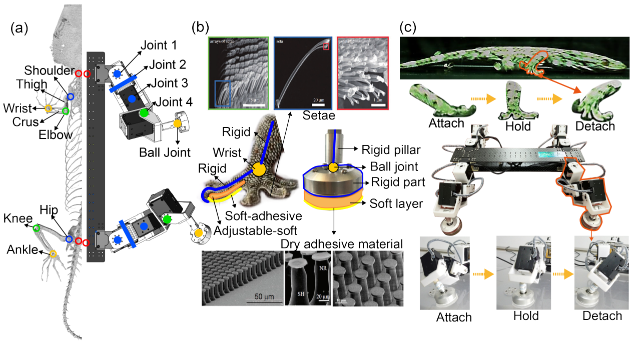

Figure 1: Design of a gecko-inspired robot. (a) The skeletal system of a gecko and the structure of the gecko-inspired robot. (b) The adhesive foot of a gecko and the robot. (c) Locomotion strategy of a gecko applied to the robot.

the attaching period to detaching period, the gecko-inspired robot completes one step of movement. After the locomotion strategy was established, the CPG combined with the RBF neural network was used to generate the complex locomotion behavior.

2.4 Body height adaptability

The body height of the gecko-inspired robot can be adjusted using infrared sensors installed on the head and tail of the robot. When it climbs a slope and encounters an obstacle, the obstacle detection signal will be active to elevate the robot's body until the signal becomes inactive. Then, the robot will overcome the obstacle while maintaining its uplifted posture, unless the tail infrared sensor detects the obstacle from behind. This completes the obstacle-overcoming process. Subsequently, the body of the robot will lower to a normal walking height.

3 Experiments and results

The robot-climbing and obstacle-overcoming experiments were performed to test the climbing ability and body-height adaptability of the gecko-inspired robot. Our experimental results (Fig. 2(b)) show that the robot can effectively climb on smooth slope of 15°. It can quickly alter its body height to climb over the obstacle on its path. In the experiment, we used an obstacle with a height of 4.5 cm. The joint movement signal of joint 4 (Fig. 2(c)) illustrates the posture change of the gecko-inspired robot during the obstacle-overcoming process. Fig. 2(d) shows the footfall diagram of the obstacle-overcoming process.

4 Conclusion

In this study, the skeletal system of an actual gecko was analyzed. Accordingly, seven degrees of freedom in each leg were determined to be necessary to provide a gecko-inspired robot with a larger work-space for climbing over an obstacle. The design principle of the adhesive mechanism used by an actual gecko was identified, and a hybrid soft-rigid foot for the gecko-inspired robot was designed accordingly.

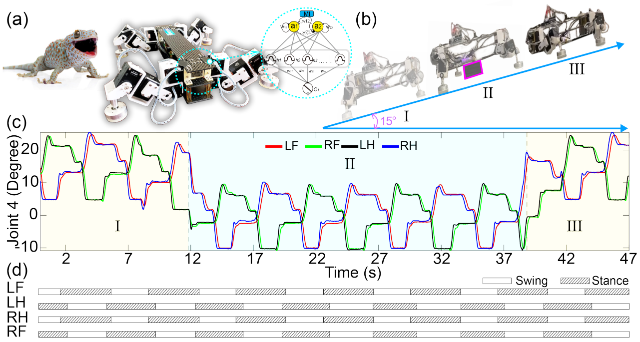

Figure 2: Climbing and obstacle-overcoming experiments. (a) Neural-network-controlled gecko-inspired robot with obstacle-overcoming ability. (b) Snapshots of robot showing the climbing and obstacle-overcoming abilities of the gecko-inspired robot. I, II, III at the bottom of the robot indicate the prior-to-obstacle period, over-obstacle period, and after-obstacle-period, respectively. (c) Movement angle of joint 4 in each leg (mainly used for body height adaptation); the shadow and roman numerals mark the corresponding period in (b). (d) Gait diagram of the gecko-inspired robot.

The locomotion strategy of a real gecko was applied to the gecko-inspired robot. Finally, the body-height adaptability of the robot was tested in an obstacle overcoming experiment. In future research, we will improve the CPG-RBF-based control to enable the robot to adapt to obstacles with different heights on slopes with different angles.

5 Acknowledgements

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