Design of a Novel Attached Foot for Space Crawling Robot

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Abstract. With the rapid development of space technology, the complexity of spacecraft is increasing and the cost of spacecraft is growing. Therefore, it is increasingly important to use space crawling robot to provide state sensing and maintenance services of large spacecraft extravehicular equipment. In order to ensure the reliable attachment of the robot to the target star in the gravity-free space environment, this paper proposes an attached foot scheme which can be applied to the space crawling robot. The proposed attached foot integrates the two technical approaches of claw grabbing and dry adhesion, which can effectively solve the repeatable attachment problem of the star surface with different characteristics. The feasibility and effectiveness of the proposed technical approaches are verified by simulation.

Keywords: space crawling robot; attached foot; claw grabbing; dry adhesion.

1. Introduction

With the rapid development of space technology, a large number of spacecraft for different tasks were developed and launched, the structure and composition of these spacecraft are becoming increasingly complicated, and performance and technical level is also constantly improving, once failure, it will cause huge losses. Therefore, it is of increasing importance to provide state perception and maintenance services for large spacecraft extravehicular equipment [1]. The development of space robots makes it possible, among them, robots that can crawl on the surface of large high-value spacecraft have received extensive attention [2].

The space crawling robot traverses the surface of the spacecraft and can carry out various tasks such as extravehicular state monitoring, fault location and diagnosis, repair and maintenance by carrying different payloads. Many researchers have proposed and developed a variety of crawling robots applied in space, focusing on light and small structure design, complex three-dimensional space crawling control, autonomous path planning, adhesion and desorption control, etc. [3, 4].

In the gravity-free space environment, the premise of space robot to carry out in-orbit services on the surface of spacecraft is that the robot can be reliably attached to the target star. However, due to different equipment and the material of different parts outside the spacecraft, the roughness of surface vary greatly, it is necessary to study the attached foot adapted to the roughness of surface. On the other hand, when the space crawling robot is crawling on the surface of the target star, frequent attachment and desorption actions need to be implemented, so the attached foot is required to be able to reliably attach to the roughness of surface and be applied repeatedly.

In order to solve the problems above, this paper proposes an attached foot that integrates two approaches of claw grabbing and dry adhesion, which can be reliably attached to the surface of different spacecraft with different roughness in the space environment. It is verified by simulation.

2. Overall design

2.1 Selection of attached foot scheme

At present, the widely used adhesion schemes mainly include magnetic adhesion, negative pressure adhesion [5], claw grabbing [6], dry adhesion [7], etc. The comparison of different technical schemes is shown in Table 1 below.

Table 1. the comparison of robot adhsion schemes

schemes	advantanges	disadvantanges
magnetic adhesion	simple to implement, strong load capacity, no noise	the adhesion surface must be magnetically conductive
negative pressure adhesion	strong load capacity，relatively mature technology	adsorption surface requires high smoothness, difficult to miniaturize devices, poor adaptability to space environment
claw grabbing	good adaptability to space environment	not adapted to smooth surfaces
dry adhesion	good adaptability to space environment, can be adapted to different surfaces of smooth materials	relatively low load capacity and technology maturity, not suitable for rough surfaces

The dry adhesion of gecko-inspired foot-hair and the claw grabbing of insect-like tarsus are two feasible attachment schemes applied in space environment. Dry adhesion is based on van der Waals force, it establishs effective adhesion to the wall through a large array of microscopic bristles, which is suitable for relatively smooth surfaces and theoretically unaffected by vacuum or temperature; Claw grabbing forms a lock with the micro-convex structure of the target surface to establish a connection through the use of spikes or hook-like structure, which is more suitable for rough surfaces. Considering that the surface materials and characteristics of the spacecraft are quite different, a functional compound bionic attached foot is designed in this paper by combining the two adhesion approaches of claw grabping and dry adhesion, hopefully to provide better adhesion effect on the target surface with different roughness.

2.2 Overall scheme

The overall structure of the attached foot is shown in Figure 1 below. The attached foot of the space crawling robot designed in this paper relies on the bionic adhesive material placed on the bottom surface of the baseplate and several pawls to achieve reliable adhesion on the surface of the spacecraft with different roughness.

The attached foot mainly includes a base plate, pawls, motor, connecting rods, springs, and shell and so on. The bottom surface of the attached foot is integrated with bionic adhesive materials, and the upper surface is used to fix related components, such as motors and support rods. The pawl structure is semi-cylindrical, one end is designed with a convex structure, and the other end is equipped with a plurality of flexible spines, which automatically adjust the expansion and angle of the spines when grasping the rough surface to improve the adaptability of the attached foot to the rough surface. The four pawl structures are uniformly installed on the bottom plate, and each pawl structure is configured with an independent transmission structure, which can realize independent and flexible rotation.

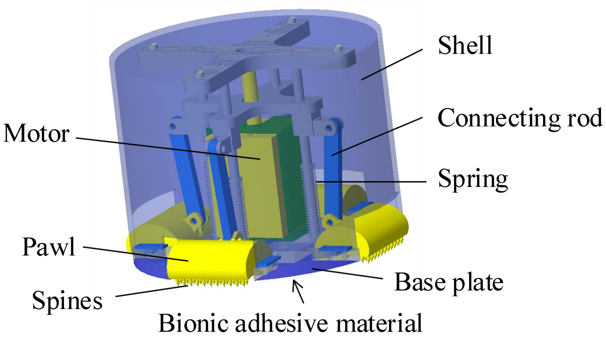


Fig. 1 Diagram of the attached foot

2.3 Working principle

2.3.1 Initial status

In the initial attitude, the moving plate of the attached foot moves to the appropriate position driven by the motor, and then drives each pawl to rotate to the appropriate angle through the connecting rod, so that the convex structure of the pawl and the spines are in a balanced position, and are not protruding from the underside of the foot, as shown in Figure (b) below. The attached foot can easily land in the initial attitude.

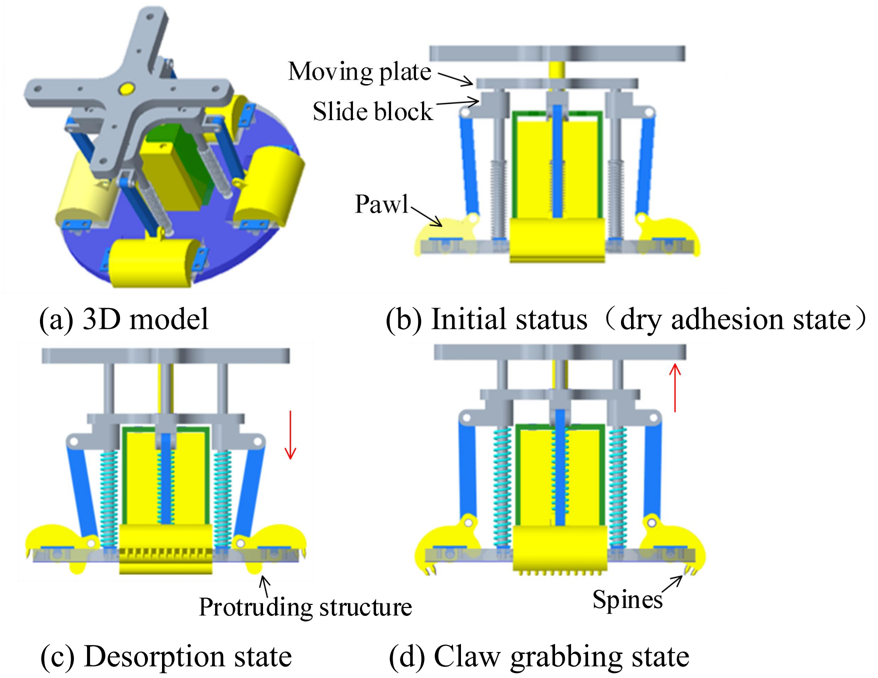


Fig. 2 Different working states of the attached foot

2.3.2 Applied to smooth surfaces

When the target surface to be attached is a smooth surface, reliable adhesion can be formed between the target surface and the bionic adhesive material integrated in the base plate of the attached foot. When the attached foot lands, the bionic adhesion material on the sole of the foot contacts with the target surface, thus a dry adhesion connection is established. At this time, the attached foot is still in the initial state.

When the attached foot needs to be detached and lifted up, the motor drives the moving plate to move down and push the slide block, thus driving the pawl to rotate. The protruding structure on the inner side of the pawl gradually protrudes out of the bottom surface of the foot, thereby lifting up the attached foot. The bionic adhesive material can be desattached with the target surface, achieving the lifting movement of the attached foot, as shown in Figure (c).

2.3.3 Applied to rough surfaces

When the target surface to be attached is a rough surface, good contact cannot be formed between the bionic adhesive material on the sole and the target surface, and the dry adhesion between the two may not be enough to ensure the normal work of the space crawling robot. At this time, the structure action of the claw spine is controlled to form an adhesion between the claw spine and the rough surface to add dry adhesion, and then form a reliable adhesion between the attached foot and the rough surface.

The specific implementation method is as follows: the motor drives the moving plate upward, and the slider also moves upward under the elastic recovery force of the compression spring, thus driving the pawl to rotate, so that the spines outside the pawl grasp the rough surface of the target to achieve adhesion. Since the adhesion is provided by the spring and belongs to the passive force, the adhesion is sufficient to maintain the adhesion state without power consumption for a long time, as shown in Figure (d).

3. Simulation analysis

Adams software was used to simulate the gripping process of the attached foot, and the Adams model of the attached foot was established, as shown in the Fig. 3. In the model, the target of the attached foot is a raised structure with a size of 4.5 cm×4.5 cm×0.5 cm. The simulation time was set to 2 s and the time step was set to 0.02 s. In the simulation, a 4mm upward displacement is applied to the moving plate. The simulation results of the gripping process are shown in Figure 4.

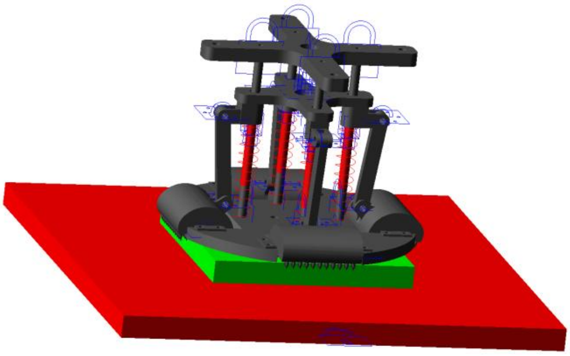
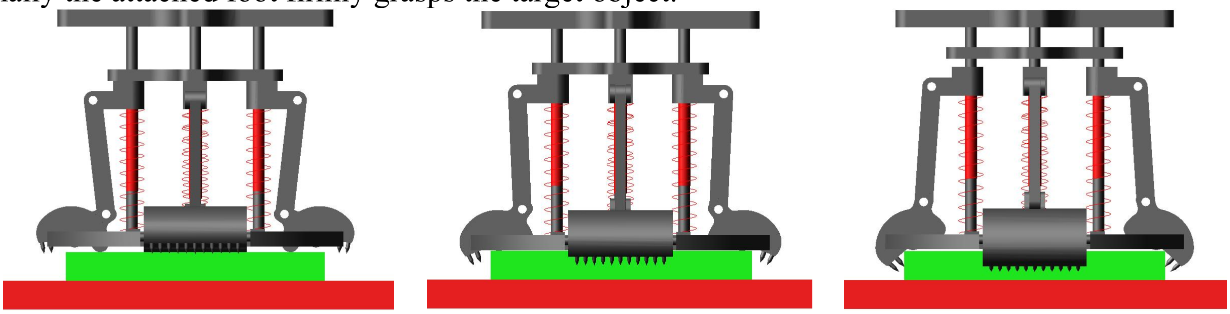


Fig. 3 the Adams model of the attached foot

As can be seen from the figure, in the whole gripping process, the moving plate moves up, the slide block slides upward under the action of the compression spring, and the pawl is driven by the connecting rod to rotate, so as to achieve the downward gripping function of the attached foot, and finally the attached foot firmly grasps the target object.



(a) Initial status (b) Beginning of gripping (c) Completion of gripping

Fig. 4 Simulation of gripping process of the attached foot

The gripping force is the key performance index of the attached foot, and the gripping force between the four pawls and the target object is analyzed in the Adams post-processing module, as shown in the figure below. When the spines attached to the foot touch the target, the gripping force increases instantaneously, and the value fluctuates continuously during the gripping process. The simulation results show that the gripping force of each pawl is stable around 1.5 N, and the overall gripping force provided by the attached foot is about 6 N.

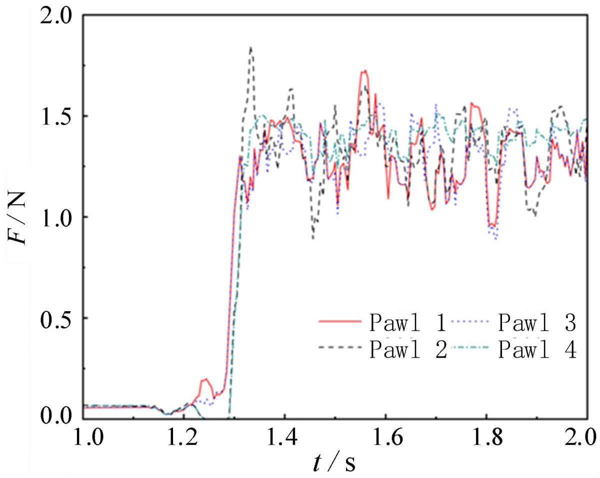


Fig. 5 Simulation results

4. Summary

Aiming at the adhesion requirements of the space crawling robot and the target spacecraft, this paper proposes an attached foot scheme which can be applied to the surface with different roughness. The proposed attached foot integrates two technical approaches of claw gripping and dry adhesion, which can effectively solve the problem problem of the star surface with different characteristics.. Adams is used to simulate the adhesion process. The results show that the current adhesion can achieve a gripping force of not less than 6N, which verifies the feasibility and effectiveness of the proposed technical scheme.

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