The Research of Adsorption Mechanism in Space Crawling Robot On-orbit Servicing for Cooperative Spacecraft

Yilin Su[1], Xuyan Hou[1]*, Kailiang Zhang[1],

Tao Chen[2], Zongquan Deng[1],Lining Sun[2],

[1] *School of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150001, P.R. China*
E-mail: hitrcamc@foxmail.com

[2] *School of Mechatronics Engineering, Soochow University, Suzhou 215000, P.R. China*

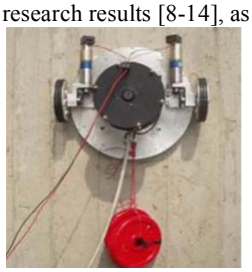
ABSTRACT

According to the on-orbit servicing requirements of space cooperative spacecraft, in order to expanded existing manipulator work space and its task function and provided support for the on-orbit control of space Cooperative spacecraft, a new type of space crawling robot was designed. The space robot system was consisted of legs driven by piezoelectric, micro adhesive feet and other parts. The space robot was composed of eight legs driven by piezoelectric which has three joints and five degrees of freedom. It can extend crossing obstacle ability by somersault based on the traditional way of crawling.The robot feet were designed into micro array structure that based on the bionics principle and reference the micro structure on feet of Gecko, insects or other creatures. Based on the theory of interface micro mechanics and tribology, the contact mechanics model between micro structure of the adhesive feet and the surface of spacecraft was established. Then analyzed its adhesive properties based on Discrete Element Method. The simulation results shown that in the space environment with zero gravity, the robot feet with micro array structure has the function of adsorption.

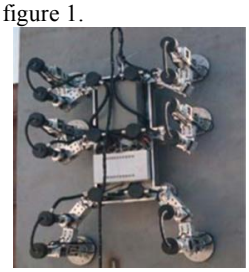
1 INTRODUCTION

Space crawling robots achieved a new spatial load control method [1-4], the robots climb in the target spacecraft surface and stick to it, to achieve a high flexibility and accessibility, and low risk. The robot is suitable for space non cooperative target on orbit control mission due to the advantages of low cost, small volume, light weight, and facilitates the main spacecraft to perform multiple tasks. The research on the space crawling robot will provide powerful support and guarantee for the space activities, which has important research value and practical meaning.

The technology of space crawling robot includes movement and adsorption generally. The adsorption technology of traditional climbing robots mainly include magnetic adsorption, negative pressure adsorption, static adsorption and chemical adhesion, etc [5-7]. Nowadays, many countries have developed for the robot, and obtained certain research results [8-14], as figure 1.

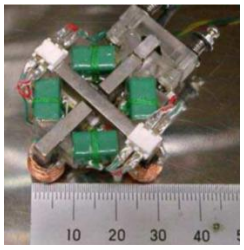


a) Alicia Robot



b) REST I Robot

c) Sky cleaner 3 Robot



d) Miniwalker Robot

Figure 1: Figure title in Italic.

The way of magnetic adhesion must adhere a wall using magnetic material, It can be adapted to variable roughness of the wall, but consumption and complex control; Negative pressure adsorption without wall material limitations, but rough surface is easy to make the suction cup leakage, reducing the adsorption force and bearing capacity, and vacuum pump has bigger noise. Electrostatic adsorption requires a conductive surface, which limits its use areas and cannot provide sufficient adhesion because of small static power commonly; Chemical adsorption consumption rapidly due to its adhesive volatile and solidified easily. All of the above adhesion technology are unable to meet the wall climbing mechanism in space.

In the process of biological evolution, geckos are able to move on walls and ceilings agilely, such ability has always been the object for researchers to focus on. The study found that the viscosity between

the gecko toes and the contact surface is the “Van der Waals force ". Van der Waals force is a weak electromagnetic force generated when the neutral molecules are very close to each other, which is a kind of dry adsorption. The micro adhesion structure of gecko feet has the advantages of large adhesion force, controlled desorption, material adaptability, no damage to the contact surface, self-cleaned, and repeatedly used compared to the traditional adhesive which is suitable for the application of the climbing robot adhesion mechanism. It has the important significance to the development of the adhesion mechanism in crawling robot foot. Therefore understanding the mechanics rules between gecko's feet and wall surface, studying adhesive arrays of gecko’s feet by using modern bionic technology is the foundation for the development of the bionic wall climbing robots.

2 THE STRUCTURE DESIGN

Combined with the unknown surface morphology characteristics of non-cooperative target, mainly considered using rotation joint, rotation joints has a stronger obstacle climbing ability that help robot cross a concave-convex surface. Traditional multi-legged robot on the earth can span a maximum height related to its structural size, while in the space environment where no gravity, it is no different between robot's top and bottom. Robot can levitate in the space, and climb obstacle by inverting itself. The obstacle that robot can climb is not affected by the robot’s structural size. The only thing need to be considered is the relationship between robotic leg size and the shape of concave-convex surface.

Through the analysis of the gecko's body structure and motion law, select a robot mechanism shown in Fig2. It has five degrees of freedom with a 2-1-2 distribution, The robot's body connecting part has two， the knee joint and the ankle joint have one and two degrees of freedom respectively. The forepart has two manipulators, it can be used for diagnosis and maintenance, this mechanism also has the following advantages after meet the above requirements:

(1) A variety of plane motion, beneficial to achieve complex tasks;

(2) Symmetrical structure, with the ability to complete tasks in any state;

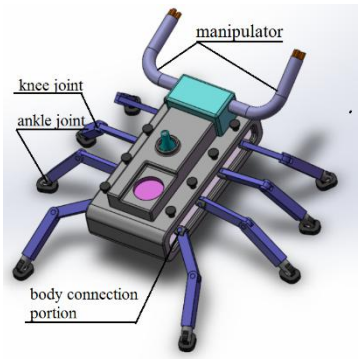


Figure 2 robot mechanism

The connection between the robot body and thigh is hip joint, between the thigh and calf is knee joint, between the calf and foot is ankle joint. Hip joint and ankle joint both have two degrees of freedom whose mechanism form is Roll-Pitch. The gravity is not considered in the space environment, so a piezoelectric motor direct drive way could be used, power transmission form is simple and practical, accord with the mechanism design guideline.

The foots of space foot climbing robot play a key role in the realization of the movement process, gait of the robot is realized by foot alternately, adhered with the contact surface and each joint drive its mechanism. In space the adhesion properties between the surface and foot has a direct impact on the robot’s reliable adhesion and motion state. In order to achieve fast and reliable adhesion between the contact surface and the foot, pelma design uses a bionic setae structure.

3 THE RESEARCH SITUATION OF GECKO ADHESION MECHANISM

The majority of gecko researches are about gecko adhesion and stripping mechanism in China and aboard. In the year 2000, Autumn (United States citizen) and his team measured single adhesion of seta on gecko foot, the result approved that the seta stick firmly to the surfaces because van der Waals' forces between the setae structures and the surface.

Under a microscope, the gecko's feet are shown in figure 3 below. The picture shows that the bottom of Gecko foot is covered with millions of fine hairs. The end of every hair is divided into about 400 to 1000 branches. There are about 5000 seta which are 30 ~ 130 microns long on the 1 mm2, nearly 500 thousand seta on one foot. There are 400 ~ 1000 spatulas on each seta. The length of spatulas is about 0.5μm, the width of spatulas is about 0.2μm, the thickness of spatulas is about 5

nm. Nano size of the spatulas contact firmly to the surfaces which make sure the feet attached to the surface

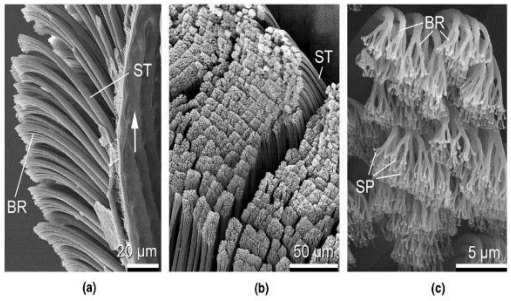


Figure 3. The gecko's foot microstructure

Figure 4 shows the gecko foot turn stickiness on and off instantly to the glass ceiling. When Gecko attached to the smooth surface, seta are toward the feet after orientation, and drawing back, flexible feet disc stretching outwards, make the hair attached to the greatest extent on the surface, increase the adhesion force; when it rests, the setae are curved inward, toward the center of the foot, the setae get straightened, without that force they unstick seamlessly.

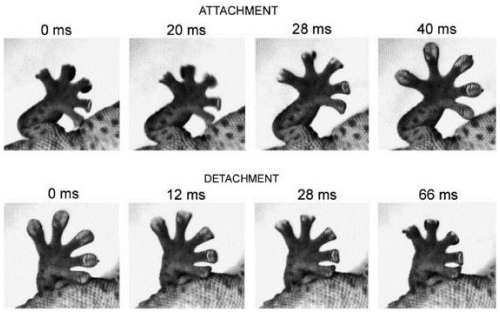


Figure 4. Snapshots of gecko attachment and detachment from a glass ceiling

Huajian gao and a team of researchers created a mathematical model that shows how the 30-degree angle of setae act on a gecko interact to create a sticking system. At a 30-degree angle, the surface area can stick to increases; an angle less than 30-degree, their sticking powers are reduced and their feet start slipping; an angle greater than 30-degree, setae will not change direction it will slide and fall off surfaces. When an angle greater than 30-degree between setae and the surface, it will make the slipping possible. [18], as shown in Figure 5.

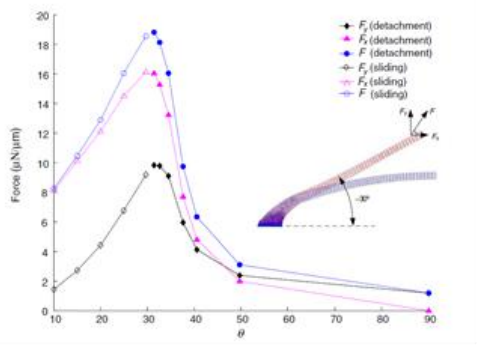
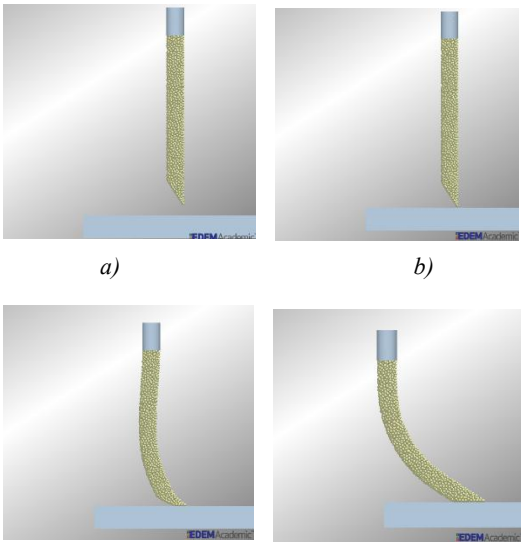


Figure 5. Analysis of the pull-off force of a single seta

4 THE SIMULATION OF ADHESION MECHANISM

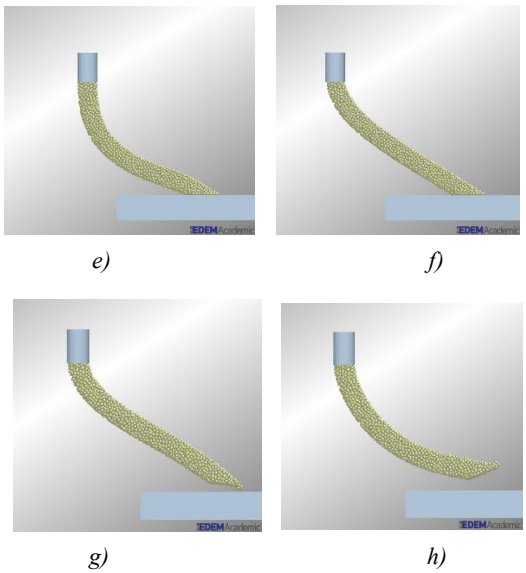
4.1 Modeling of a single seta based on discrete element

In the actual crawling, the seta of the gecko make an angle with its sole, and under the effect of elastic force by the contact surface. So it is necessary to analyze the adhesion effect between single seta and contact surface. Follow the example of the gecko seta structure, establish a single fiber model of tilted micro array based on discrete element method. Assuming the fiber's material as same as the gecko seta's material. The interaction of particle to particle in single fiber is Hertz-mindlin with bonding. The interaction of particle to particle between single fiber and contact surface is Hertz-mindlin with JKR. The radius of the single fiber is 0.02mm, particle radius is 0.003mm and work of adhesion is 2mJ/m2. As shown in Figure 6, analyze the fiber's adhesive properties by pressing the fiber on the surface first and then stretch the fiber out of the contact surface.



a) *b)*

c) *d)*



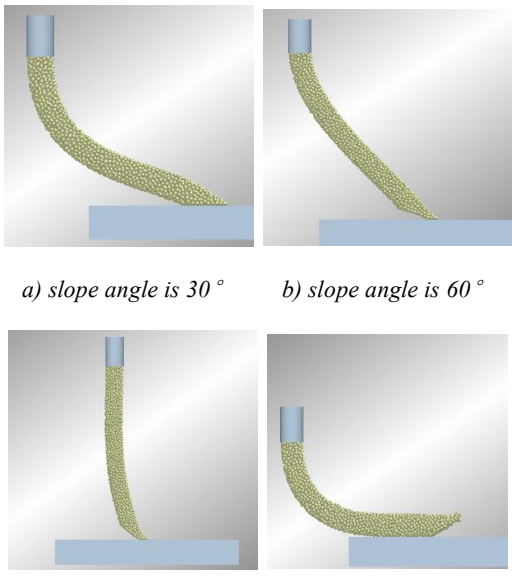
e) *f)*

g) *h)*

Figure 6. The simulation process of single fiber based on discrete element method

4.2 The result of simulation and analysis

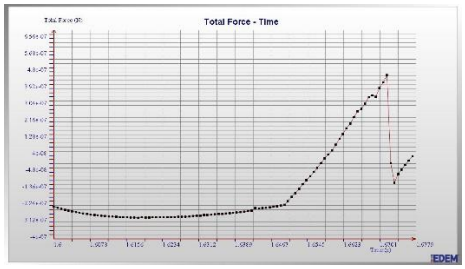
Based on the above parameters, according to different slope angle between the fiber and the contact surface, using discrete element software to simulate the process of adhesive with single fiber in five kinds of contact status. Get the maximum adhesion force with different slope angle. The simulation model of single fiber with different slope angle as shown in Figure 7. The normal stress curve of single fiber with different slope angle as shown in Figure 8.



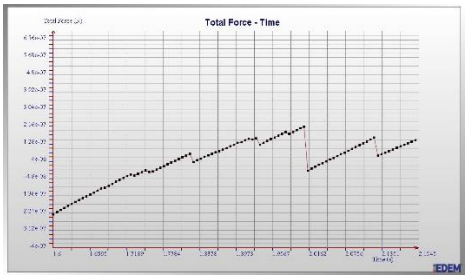
a) slope angle is 30 ° *b) slope angle is 60 °*

c) slope angle is 90 ° *d) slope angle is 0 °*

Figure 7. The simulation model of single fiber with different slope angle



a) slope angle is 30 °



b) slope angle is 60 °

c) slope angle is 90 °

d) slope angle is 0 °

Figure 8. The normal stress curve of single fiber with different slope angle

We could see from the curve, the maximum adhesive force is 4.63e-7N when the slope angle is 30°. With the increase of slope angle the adhesive force of single fiber become lower and lower. The adhesive force is only 0.98e-7N when the slope angle is 90°.

When the slope angle become 0°, the side of fiber is

contact with surface. The fiber structure was destroyed by large pressure make failure to its adhesion properties.

5 CONCLUSION

This paper proposed a new type of space crawling robot. The robot micro adhesive feet were designed into micro array structure that based on the bionics principle and reference the micro structure on feet of Gecko. Based on the theory of interface micro mechanics and tribology, using discrete element software to establish the simulation model. Modeling analysis the gecko's adhesive ability and the rapid stripping ability. Establish a mechanical model of single seta in different conditions. Simulate the adhesion and stripping process of the seta at different angle. Analysis the adhesive property of a single seta. The simulation results demonstrate that using different ways of movement can achieve different adhesive ability of single seta. The results provides theoretical support for achieving the robot foot adhesion and rapid stripping ability.

Appendix

Appendixes appears before the acknowledgment.

Acknowledgement

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