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Design and Application of Wheel-legged Hexapod Robot

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Abstract

In order to adapt the robot to various rugged terrain and work normally in different terrain, our team independently developed a six-legged robot with a one-piece structure. On a smooth road surface, the robot uses the wheel structure, in rough terrain, the robot uses the foot structure, which makes the robot can be more effective and convenient to move to human inaccessible areas, such as space, mountains, mines, and so on. Using Solidworks and UG modeling and kinematic simulation in Adams, my team successfully simulated the specific structure and moving gait of this robot.

Keywords

Hexapod robot; Triangular gait; Wheel and foot integration; Unstructured terrain; Adams simulation; Solidworks modeling.

1. Background

1.1 State of the robot industry

Since the reform and opening-up, China's science and technology have been changing with each passing day. Many new scientific and academic achievements have been widely used in various fields, providing impetus and scientific and technological strength for national construction. Among them, industrial robots, as a representative of advanced and sophisticated industrial equipment, have been gradually applied in civil, industrial, and military fields, and have a profound impact on the development of today's society.

An industrial robot is a set of electronics, control, computer, artificial intelligence, machinery, and other disciplines in one of the highly sophisticated modern equipment. The use of industrial robots can guarantee the personal safety of workers, improve the working environment, reduce labor cost and intensity, solve the problem of labor shortage, and greatly improve labor productivity. Therefore, the manufacturing and application level of robots reflects the technological level and height of a country's manufacturing industry. With the development of robotics technology, China has gradually grown into the world's largest industrial robot market. According to the data released by the International Federation of Robotics and the Chinese Institute of Electronics in 2019, the annual growth rate of China's robot market was as high as 20.9 percent from 2014 to 2019, with a market value of nearly 8.7 billion US dollars, including 5.7 billion US dollars for industrial robots, 2.2 billion

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US dollars for service robots and 800 million US dollars for special robots. (See Figure 1)Industrial robots are still the main development direction of robots [1].

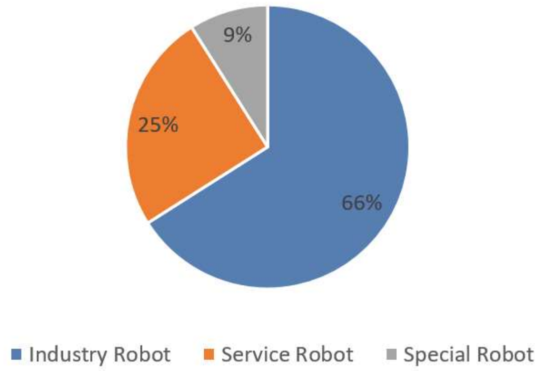

Figure 1. Robot market structure in China in 2019

According to the *China Robot Industry Development Report* (2019), As of 2018, China ranked first in patent applications with 230,960 among major developing countries and regions in the global robot industry, which is far more than Japan, Europe and the United States [1]. (See Figure 2)

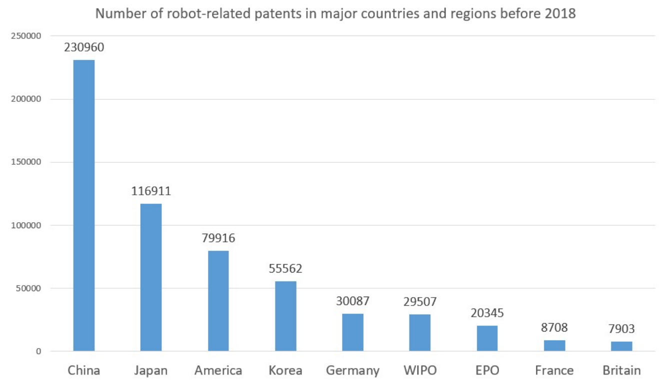

Figure 2. Number of robot-related patents in major countries and regions before 2018

1.2 Research status of hexapod robot

Bionics is a discipline that applies biological science to engineering technology, improving existing or creating new mechanical structures by imitating biological functional structures (Zhang Xiuli, 2002). The robot is one of its main fields of combination and application. Among them, the research of hexapod robots has aroused great interest and attention from researchers all over the world and has achieved a lot of scientific research results. Genghis, a hexapod robot for planetary exploration, was developed by the Massachusetts Institute of Technology in the 1980s [2] (Figure 3).

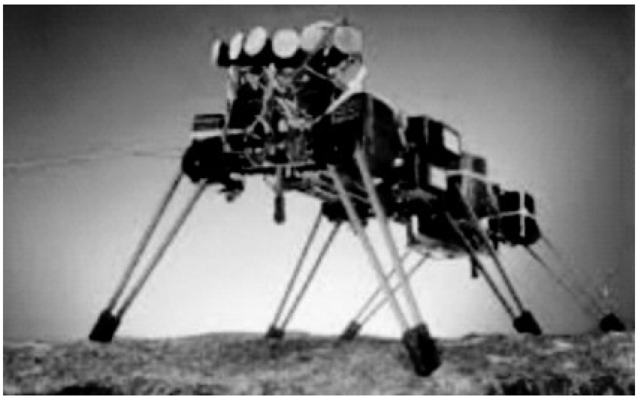

Figure 3. Hexapod robot Genghis

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The domestic development of hexapod robots has also achieved fruitful results. Harbin Engineering University has developed a crab-like robot [3]， and DTWN frame bipedal robot was developed by Tsinghua University [4].

The hexapod robot has the characteristics of rich gaits and flexible structure. The structure from the mechanical leg to the structural arrangement of the whole machine mostly includes the concept of bionics. In the structural design of the mechanical leg, the distance dimension ratio between each joint is selected according to the size of the insect's leg (as shown in Figure 4).

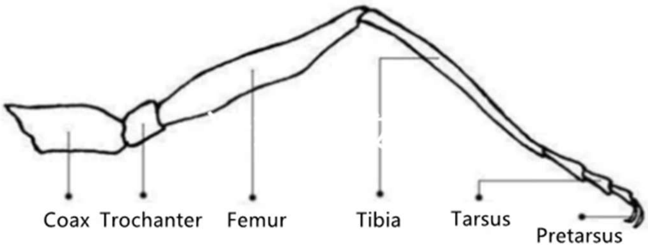

Figure 4. Insect leg structure

When the hexapod robot moves, it mainly moves alternately with a triangular gait. That is, the six legs of the robot are divided into two groups, with the front and rear feet on one side of the body and the middle foot on the other side as one group, forming a stable triangular structure. When marching, only one group is marching and the other is supporting at any one time. The triangle gait motion diagram of the robot is shown in Figure 5 [5].

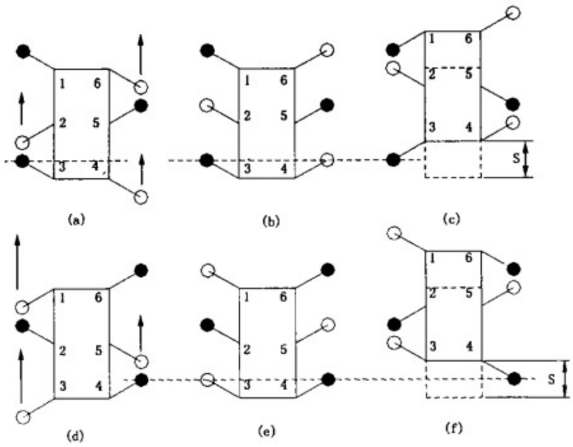

Figure 5. Schematic diagram of triangular gait of robot

1.3 Application and disadvantages of hexapod robot

Based on the characteristics of rich gait, flexible structure, and strong stability, the hexapod robot can adapt to complex unstructured terrain and can pass obstacles that are difficult or even impossible for wheeled robots or tracked robots to pass, so it has high adaptability to the natural environment. Therefore, a hexapod robot has great application potential in inspection, express delivery, disaster rescue, guide blind social assistance, and other fields.

However, the hexapod robot still has many drawbacks. First, compared with the wheeled robot on a flat road, its speed is slow and its work efficiency is low. Second, the structure and control algorithm of the hexapod robot is complex, and the research and development, and production cost are high. In addition, the balance between stability and flexibility is still a big problem for hexapod robots to overcome.

1.4 Aim of our research

Based on the advantages and disadvantages of a wheeled robot and hexapod walking robot, a hexapod robot is designed. The team members used Solid Works to carry out mechanical structure modeling

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and used Adams software to simulate the wheel forward, turn, triangle gait alternating forward, turn and foot state obstacle crossing ability. To explore the feasibility and practicability of a hexapod robot.

1.5 Literature review

Research on mobile robots began in the late 1960s. At that time, Nils Nilssen and Charles Rosen of Stanford Research Institute developed an autonomous mobile robot known as Shakey to study the planning and control ability of robots in complex environments [6].

In 2002, Li Lei, Ye Tao et al from the Institute of Automation [7], Chinese Academy of Sciences described the research status of mobile robot technology and made a prediction for future development. According to the operating space, they divided the robot into the land mobile robot, underwater robot, unmanned aircraft, and space robot. The integrated robot with wheels and feet studied in this paper is the land mobile robot.The main research interests of mobile robots include navigation and path planning, multi-sensor information fusion, mechanism design combined with bionics, and network robots.

Now the function of industrial robots has been refined, derived a variety of robots with specific functions. In 2021, Hu Heyu, Cao Jianfu et al [8] studied and analyzed the position/force hybrid control method of curtain wall mounting robot, summarized the force analysis of curtain wall mounting robot, and promoted the establishment of the dynamic model and the design of the controller. In the same year, Yu Zhenglin, Sui Tianshan et al [9] carried out the mechanism design and motion analysis of the six-legged explosive disposal robot and expounded the overall mechanical structure design and trajectory planning.

The control algorithm is one of the core functions of a robot. In 2021, Qin Shanghou, Guo Gan et al. [10] took Siemens SMART 200 PLC as the core controller to carry out research to reduce the labor cost of warehousing and logistics and improve production efficiency. In the same year, Li Jianing, Han Dan et al [11] designed the gait optimization system based on a genetic algorithm, improved the design of the control system, and achieved the control effect of autonomous walking of the robot. Chang Lu, Shan Liang et al [12] studied formation control of multi-robot based on improved DWA in an unknown environment. By improving the dynamic window algorithm, they enhance the robot's navigation ability and global search ability under an unknown environment and design the control strategy based on DWA and the social force model (SFM).

Through a variety of literature research, we found that the research on hexapod robots has become a hot topic. In 2015, Liu Qingyun and Jing Tiantian [13] analyzed the research status of the hexapod robot from the aspects of gait planning and trajectory planning. Li Manhong et al. [14] analyzed and discussed the development status and future planning of hexapod robots from the aspects of bionic structure design, gait planning, and multi-legged coordinated control, which restrict the development of the hexapod robot. Liu Yan et al. [15] analyzed the posture of the hexapod robot under the triangular gait, deduced the relationship between the angles of different foot joints, and used ADAMS for simulation. In 2021, Hu Yong et al. [16] used ADAMS software to analyze the motion state of the hexapod robot in the unstructured environment and obtained the dynamic model.

With the advent of the era of artificial intelligence, the robot-related fields gradually shift from machine intelligence to artificial intelligence and combine with the Internet to achieve more powerful functions. In 2021, Xinyue Yang [17] conducted path research on industrial robots under the background of "Internet +", and expounded the disadvantages of robot development and countermeasures. Yang Wenyu et al. [18] explored the internet-based distance experiment teaching of mobile robot course, proved the feasibility of distance teaching of the robot, and clarified the future development direction of distance experiment teaching. While ARTIFICIAL intelligence is booming, we should also look at the ethical, moral issues and technological risks it may bring. In 2017, Wu Handong [19] discussed the institutional arrangements and legal regulations in the era of ARTIFICIAL intelligence, analyzed the social risks brought by ARTIFICIAL intelligence, and proposed effective measures such as special legislation and the formation of a law-based risk management and control mechanism.

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Through literature analysis, it can be seen that the current robot industry is booming, with detailed robot types and various uses. The research on hexapod robots and their structure and gait are one of the hot topics at present. The combination of robots, artificial intelligence, and the Internet is the future development direction.

2. Method

2.1 Machine Design

Our core design concept is to combine the advantages of the Hexapod robot and the Wheeled robot, allowing robots to deal with difficult terrain and move quickly. So we designed a robot with wheels and feet, which can adjust to different modes when meeting different kinds of situations.

(1) A hexagonal body

In the mechanical design, we choose the regular hexagon structure as our basic framework， which gives our robot satisfied flexibility and adaptability. With such kind of structure and the universal wheel, the helped robot in the wheeled state can move in all directions and quickly changed its orientation. This symmetrical structure also makes it more stable when switching to a foot robot. The body shell is made of lightweight but strong materials, making the robot flexible while resisting pressure

(2) The structure of the foot

In the design of the robot foot, we mimic the structure of the insect foot. It has three free joints, enabling it to quickly adjust posture to overcome obstacles. At the same time, it can keep the center of mass steady during the movement.

(3) Wheel-foot conversion

To realize the wheel-foot conversion, we design a clip structure. The motor drives the gear to control the foot wheel. When the gear is raised, the foot wheel can roll freely, and our robot can move quickly. When the gears are pressed down, the wheels lock, and our robot shifts into a foot posture to deal with difficult terrain.

(4) The structure of the body and components in it

The robot is equipped with some basic control components, such as the battery, electrical machinery, control panel, to achieve the basic control of the robot. On top of that, the robot is also equipped with wifi, cameras, ultrasonic detectors, and other wireless communications devices, which allow it to perform difficult tasks, including search and rescue and reconnaissance.

(5)Tools

We use UG and SolidWorks to achieve the design of the robot. We finished detailed modeling of each component, the optimization of the structure, and the final assembly. Adjusted the ratio of the feet to the body to make them more coordinated and stable. The positions of components and the rotation angles of each joint are determined. So that our later simulation experiment can be carried out normally.

2.2 Kinematical Simulation Tool

To simulate the motion of the robot, we use ADAMS software to carry out the simulation experiment. First, we put constraints and motions on the joints, so that they can rotate in the experiment as we would expect them to.

Table 1. Physical constants used in the experiment

Gravitational acceleration	Kinetic friction coefficient	Static friction factor
9.803m/s^2	0.4	0.5

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As shown in Table 1, in the experiment, we achieved the simulation of the real-life situation in the software by limiting the physical constant coefficient.

3. Consequence

3.1 Physical Structure

(1) In this paper, a hexped robot is designed, which can simultaneously move at high speed on smooth road surface and can also walk flexibly in unstructured terrain such as mountains, woodlands and hills

(2)Traditional multi-legged robots have good terrain adaptability and excellent stability. They can move efficiently on unstructured terrain but have disadvantages such as slow-moving speed and low work efficiency on flat pavement. And the transmission of a crawler or wheeled robot can move at high speed on the flat road surface, high flexibility, but its adaptability is poor, the working terrain requirements are high shortcomings. Therefore, the advantages of the two kinds of robots are combined in this paper. The overall design diagram is shown in Figure 6. The designed single-legged Hexapod robot is mainly composed of a polygonal body, six groups of evenly and symmetrically distributed wheels and legs, and electronic components inside the body. The structure has good stability, strong mobility, and good bearing capacity under working conditions. It can not only move on the smooth road surface with high speed and efficiency but also move flexibly on the unstructured terrain. Moreover, the Hexapod robot has more degrees of freedom than the biped and quadruped robot, and the way of adjusting the center of gravity on the rough road surface is more flexible and more stable.

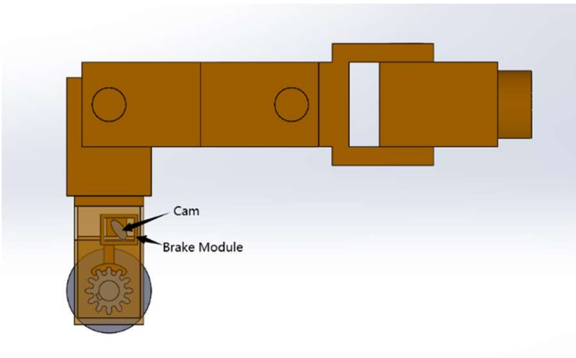
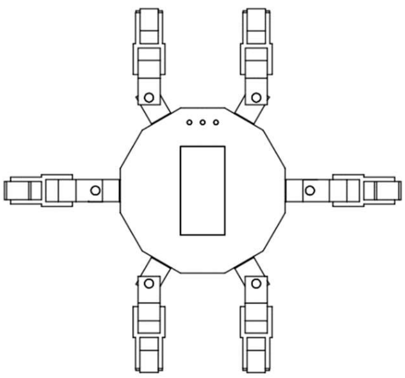


Figure 6. The structure of the leg

(3) Gait Planning In the wheeled fast-moving gait, the posture of the robot is shown in Figure 7. The front and back four legs are parallel to the direction of travel so that the robot moves at a high speed, while the middle two legs are perpendicular to the direction of travel to improve the stability of movement. As shown in Figures 8 and 9, legs 1, 3, and 5 or 2, 4, and 6 form support point to support the fuselage during each movement, and the movement is completed by swinging back and forth of legs 2, 4, and 6 or 1, 3 and 5.



Figre 7. Wheeled moving gait

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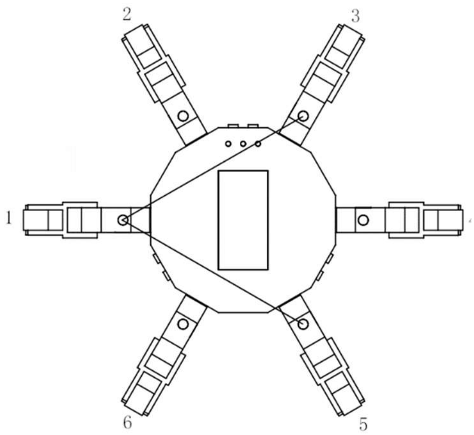

Figure8. Triangle gait 1

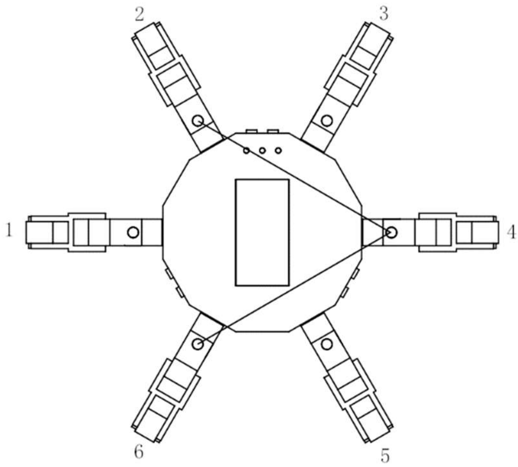

Figure 9. Triangle gait 2

(4) The sensor design is shown in Figure. 5. Three cameras and three ultrasonic rangefinders are respectively set at 120 intervals on the six sides of the fuselage for image recognition and obstacle avoidance.

3.2 Kinematical Simulation

Table 2. Some properties of robots

Body length	Body width	Height	Foot length	Wheel radius
30cm	30cm	15cm	25cm	3cm

Table 2 shows some basic properties of robot we set when we achieved the simulation.

(1) Adams is used to carry out kinematic simulation to simulate the possibility of using wheel fast movement. It can be seen from figure 10 to figure 11 that the wheel foot integrated robot moves quickly.

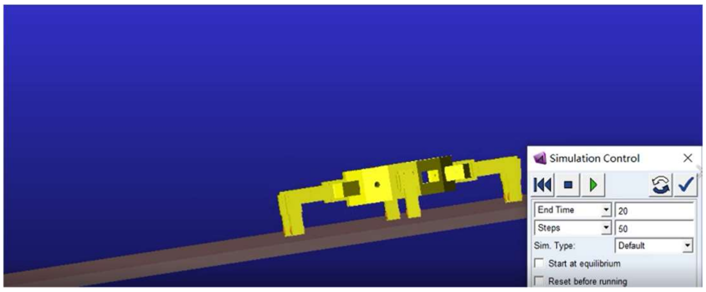

Figure 10. Initial position of wheeled postion

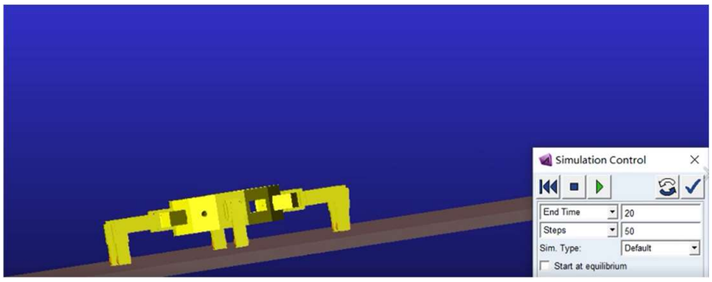

Figure 11. End position of wheeled postion

(2) Triangle gait

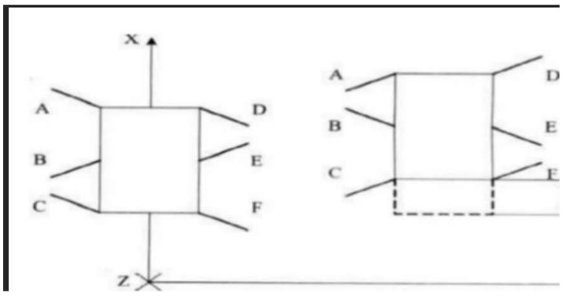

Figure 12. Triangle gait

Figure 12 is a simple illustration of the principle of the triangular again achieving the foot movement and steering of the robot, we mimic the triangulated gait of insects. To achieve a stable body movement form.

In the Adams, we use some specific functions to realize the sequential and periodic movement of the robot joint.

Function 1: Xd*time

It can achieve the basic motion of the machine (angular rotation or displacement)

Function 2: Step STEP (time, t0,h0,t1,h1)

It can control the joint to rotate a certain Angle(H1-H0) for a certain period of time (t0-t1).

Function 3: STEP+mod STEP (mod(time,T), t0,h0,t1,h1)

It can control the joint to rotate a certain Angle(H1-H0) for a certain period of time (t0-t1), and T as a period.

In the gait simulation experiment, we set the time for the joint to complete a movement as 3s and the movement Angle as 30d to achieve a stable triangular gait.

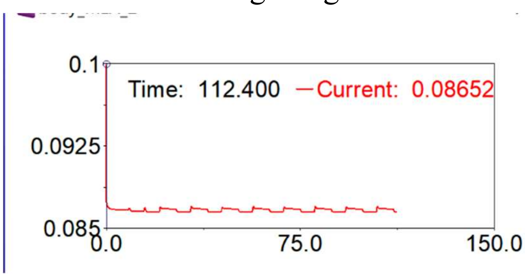

Figure 13 The height position of the center during the movement

The height position of the center of mass of the robot changes during the movement

From the figure 13, we can see that under this parameter setting, the motion of the robot is relatively stable.

To complete the experiment of crossing the obstacle, we designed a staircase. To complete the experiment of crossing the obstacle, we designed a staircase. The steps are 50cm long, 10cm wide, and each step is 5cm high. The simulation results show that the robot can easily overcome the obstacles or directly avoid the obstacles by using a simple triangular gait.

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he Step function is still used in the simulation of steering gait, and 45°, 90° and 180° steering are simulated for wheeled state. Simulation of 45°, 90°, 135° and 180° steering was carried out for foot state. Figure. 14 shows the steering movement path in wheeled mode. Figure. 15- Figure.18 show the steering process in foot mode.

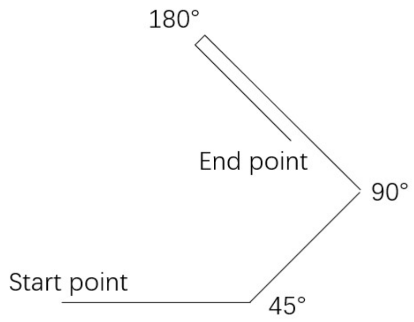

Figure 14. Wheeled state steering motion diagram

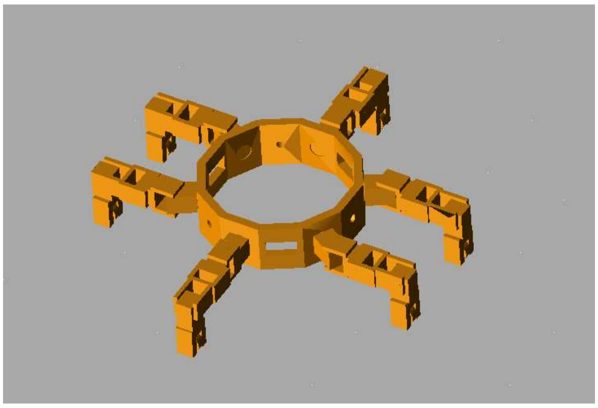

Figure 15. Initial state

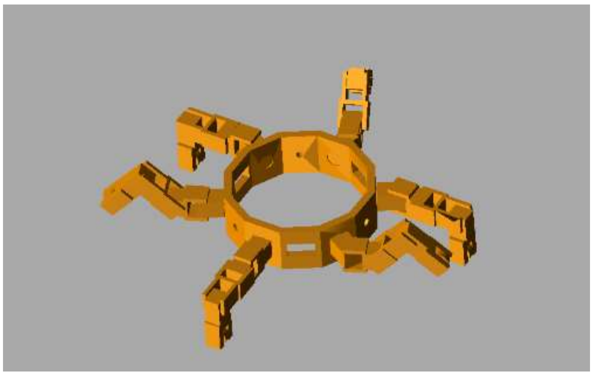

Figure 16. A set of mechanical leg lifts

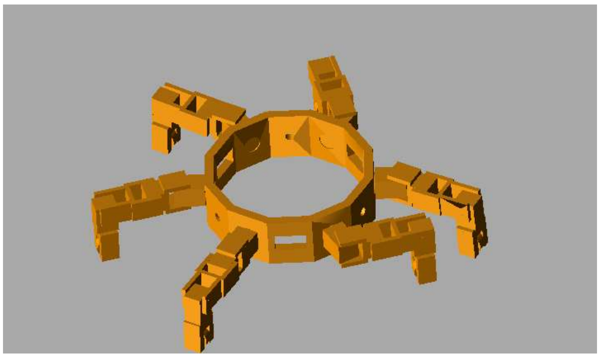

Figure 17. The rotation of a set of mechanical legs

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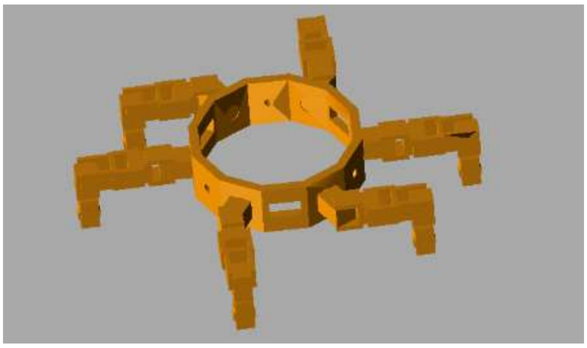

Figure 18. The grip and steering of the mechanical leg

(4) In terms of obstacle surmounting ability, this paper designs three steps with each step width of 60mm and each step height of 10mm to verify the obstacle surmounting ability of the wheel-foot integrated robot. Figure 19- Figure 21 shows the obstacle surmounting process of the robot.

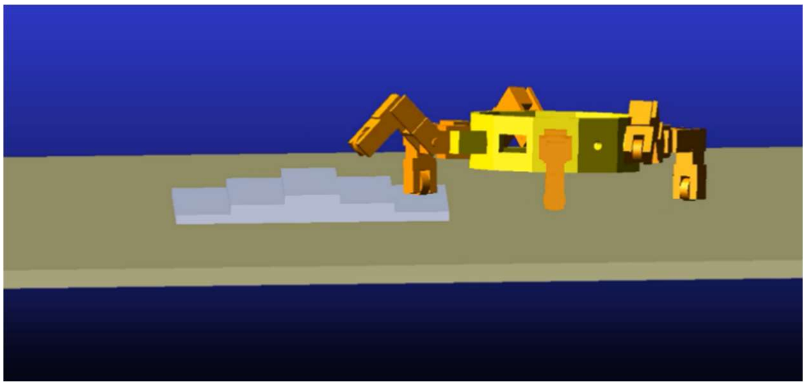

Figure 19. The start of the obstacle-surmounting

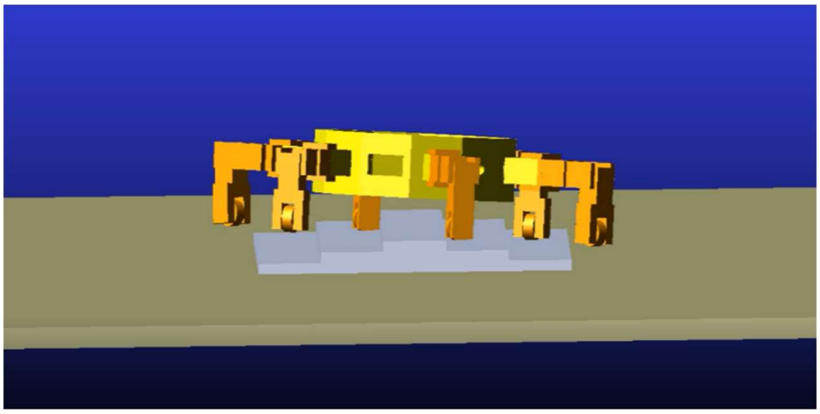

Figure 20. The process of the obstacle-surmounting

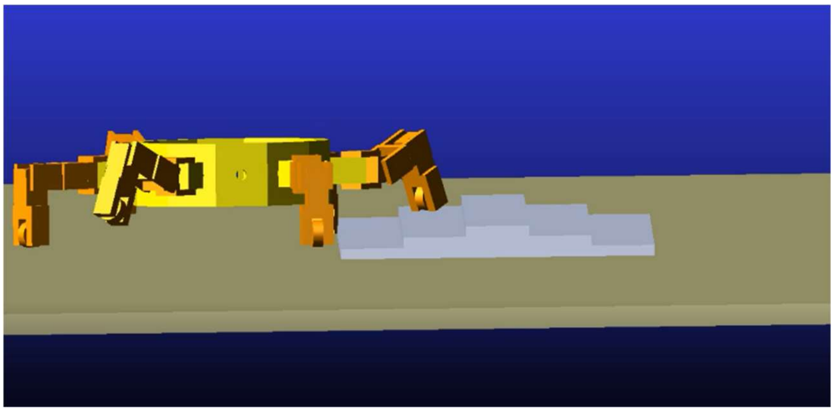

Figure 21. The end of the obstacle-surmounting

4. Discussion

4.1 Benefits and drawbacks

In this paper, the design of the wheel foot one-piece six-legged robot combines wheeled or tracked, the advantages of both two feet and four feet robot also make up the disadvantages of the two, with strong maneuverability on a flat road, high flexibility, and strong adaptability in unstructured terrain mountain at its advantages, at the same time, compared to six foot two feet and four feet robot load ability is stronger, more stable, So the fuselage is much more scalable and you can imagine having a robotic arm on the fuselage to grab things and so on. However, the robot also has some shortcomings. For example, in the aspect of mechanism, the robot has more leg joints, which leads to greater control difficulty than other types of robots. In the aspect of parts loss, because it has six legs, the loss of the same parts will also be greater.

4.2 Future Working

We hope that the integration of wheel and foot can not only be a hexapod robot in the field of robotics, but also other types of robots can be promoted and applied, and the advantages of wheel and foot can be fully exploited to combine a more efficient integration of wheel and foot solution

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