The wheel-step planetary exploration vehicle with two-way stable obstacle-crossing function

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Abstract. Planetary exploration has always been an important topic in China's aerospace field. On the rugged planet surface, having a good obstacle-crossing ability is crucial to the mission of the planetary exploration mobile system. In this paper, after consulting the data of planetary vehicles at home and abroad, and analyzing the current suspension structure of wheeled planetary exploration vehicles at home and abroad, a six-wheel planetary exploration vehicle with a certain obstacle-crossing capability and capable of bidirectional driving is designed.

1. Introduction
With the development of the times, the exploration of the universe has increasingly become the focus of people's research in the scientific field. By referring to relevant literature, the advantages and disadvantages of various planetary exploration vehicles are summarized, and a wheel-step planetary exploration vehicle that can be driven bidirectionally and has the ability to actively overcome obstacles is finally designed.

2. Research status
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2.1. Research status of wheel-step planetary exploration vehicles at home and abroad

2.1.1 Research Status of Foreign Wheel-step Planetary Exploration Vehicles
(a.) Russian Marsokhod Mars rover
The Marsokhod principle prototype developed by Russia adopts six-wheel independent drive and three-stage articulated suspension system (as shown in the figure 1 and figure 2). It has unique structure and strong obstacle-crossing capability. The site is flexible and can change shape passively according to the terrain. The car body is divided into three sections. In addition to the rotation of the wheels and the degrees of freedom, it can produce torsional rearing and yaw to act as a sports posture. There are 12 degrees of freedom on the left and right, and it can cross 0.5m obstacles.
A series of planetary exploration vehicles designed by NASA. The Curiosity, 3m×2.8m×2.1m, 899kg, six-wheel independent drive, coordinated steering, wheel diameter 50cm, 6-wheel coordinated movement makes it have a 1 meter obstacle clearance capability. Rocky7 (as shown in the figure 3 and 4) in the Rocky series uses six-wheel rocker suspension - Type mechanical structure, equipped with a sun attitude sensor, three quartz gyro accelerators, wheel optical encoders, can grab the dumping stones; the structure of Sojna is similar to Rocky4, using six-wheel rocker suspension type, 4 on the corner. Each wheel has drive and control capabilities, a total of ten drive components. The rocker arm is connected to the vehicle body through a hinge point of a differential device, one segment is connected to the wheel, and the other end is connected to the swing bar through the hinge point. Both ends of the swing bar are connected to the wheel. This structure is simple and stable[1].

2.1.2 Research status of domestic wheel-step planetary exploration vehicles
(a.) Active Suspension Rover designed by Harbin Institute of Technology
The rocker-bogie type suspension differential mechanism adopted by Harbin Institute of Technology makes the planet car have a good ride (as shown in the figure 5). The axis where the output shaft of the differential is located is called the pivot. The front section of the main rocker arm and the rear section of the main rocker arm are independent. The rotation of the front and rear sections of the main rocker arm around the pivot axis also realizes the linear correlation of the two rotations. The advantage is that the mechanical equipment is simple; the differential speed effect is good, the speed regulation accuracy is high, and the operation is stable.

(b.) Active Suspension Rover designed by Harbin Institute of Technology
The National Defense Science and Technology University double crank slider lunar rover is symmetrically distributed and adopts special spring connection, which greatly improves the stability of the vehicle body and the passive adaptability of the ground (as shown in the figure 6). By separately controlling the two sliders, the connecting rod is driven by the crank, and finally the active obstacle crossing of the middle wheel and the front wheel is achieved. The disadvantage is that the suspension structure is complex, requires high precision, and poor reliability in the space environment.
2.2. Brief analysis of literature review at home and abroad
Based on the existing research results: due to the harsh natural conditions such as the complicated terrain of Mars and large dust, the design of a relatively simple suspension structure will reduce the damage rate to a certain extent. After a comparative analysis, it was found that most planetary exploration vehicles only have a unidirectional drive structure. Compared with the four-wheel mechanism, the six-wheel mechanism has higher stability. Based on the above analysis of the domestic and foreign research status, this article intends to conduct research on six-wheel active suspension planetary vehicles to adapt to complex terrain[2].

3. Designing part
The wheel-step planetary exploration vehicle with two-way stable obstacle-crossing function can realize the function of two-way obstacle-crossing through electric push rod and telescopic. It consists of three parts: car body, driving set and passive wheel set (as shown in the figure 7)[3].

3.1. Institutional design
The wheel-step planetary exploration vehicle with two-way stable obstacle-crossing function borrows from the Marsokhod Mars exploration vehicle's "creeping" mode of travel. The advantage of "creeping" travel mode is that it can adapt to different types of ground. The car body can be divided into three sections: front wheel, middle wheel and rear wheel. The frame between the front wheel, middle wheel and the middle wheel rear wheel is sequentially extended and shortened, so that the entire lunar rover exhibits a creeping posture to achieve climbing. Over-obstacle function. The comparison of the obstacle crossing performance of the four-, five-, six-, and eight-wheel planetary exploration vehicles and the stability of the whole vehicle in the bidding shows that the six-wheel planetary vehicle has higher stability. Therefore, we will improve on the basis of the structure of the six-wheel creeping planetary exploration vehicle. Considering that most planetary exploration vehicles only have a unidirectional driving structure, the lunar rover designed in this paper belongs to a centrally symmetric structure, that is, the whole vehicle is symmetrical left and right, and symmetrical front and rear[4].
According to the actual needs of active obstacle crossing, based on the existing data of the six-wheel rocker rocker structure of the series of lunar rover developed and launched by the United States, such as Curiosity, Courage and Opportunity, we designed the electric push rod as the main obstacle crossing Power, the travel structure of the wheel-step planetary exploration vehicle including the four-bar structure (as shown in the figure 8).

Figure 8. the overall schematic diagram of the wheel-step planetary exploration vehicle
The structure can be divided into three parts: car body, driving wheel set and passive wheel set. The upper side of the car is equipped with a solar light sensitive plate, which is used as the power source of the whole car. Compared with nuclear power generation, this method makes the vehicle more lightweight and does not have the problem of detecting power exhaustion outside. The inside of the car body is used to carry various planetary detection equipment, the sealed car has a large capacity, and it is not easy to cause excessive wear of the detection device due to falling moon dust.

3.2. Structural design
(a.) Active wheel set-active obstacle-crossing structure
The driving wheel set adopts a four-bar mechanism to achieve the obstacle-crossing function of the wheel set with the thrust of the electric push rod. The car body, the driving wheel group connecting rod, the electric push rod and the passive wheel group supporting rod form a four-bar structure (as shown in the figure 9). Among them, the support wheel of the passive wheel set is fixedly connected to the car body and the electric push rod; the connecting rod of the active wheel set is hinged between the car body and the electric push rod using a hinge. When an obstacle is encountered during traveling, the electric push rod is extended, and the connecting rod of the driving wheel set is lifted upward under the action of the electric push rod to cross the obstacle.

Figure 9. schematic diagram of the active obstacle-crossing structure of the exploration vehicle
(b.) Passive wheel set-limit structure
For the structure of the passive wheel set, we designed it like this: the supporting rod of the passive wheel set is composed of a hollow outer cylinder and a thin rod. The role of the passive wheel set is to adapt to the terrain, change the height of the wheels according to the ground fluctuations, so that the wheels are attached to the ground to the greatest extent, and maintain the stability of the body. There is a spring limit device inside the outer cylinder. The upper end is connected with the thin
rod, and the lower end is connected with the car body. When the ground encounters a protrusion, due to the limitation of the spring, the passive wheel set is always in contact with the ground (as shown in the figure 10).

Figure 10. the limit structure of the passive wheel set of the exploration vehicle

(c.) Reducer-harmonic gear reducer structure
The six wheels of the whole vehicle are equipped with a braking structure with a reducer. The car borrows from the harmonic gear reducer of the Apollo lunar rover (as shown in the figure 11). The harmonic gear reducer is composed of a fixed internal tooth rigid wheel, a flexible wheel, and a wave generator that radially deforms the flexible wheel. It uses a flexible gear to produce a controllable elastic deformation, causing the rigid wheel and the flexible wheel. The teeth are relatively staggered to transmit power and movement. Harmonic gear reducers have the advantages of high precision and high bearing capacity. Compared with ordinary reducers, because the materials used are 50% less, their volume and weight are reduced by at least 1/3.

Figure 11. schematic diagram of the harmonic gear reduction of the exploration vehicle

(d.) Wheel design-hollow wheel design
For the wheel part, we choose the design method of the hollow wheel. Compared with the solid wheel, the weight is lighter, and when the wheel enters the sand, it can slide out from the other side to prevent the accumulation of moon dust and reduce the loss of the hub axle. The surface of the wheel is provided with zigzag protrusions, which enhances the grip when driving on uneven ground. The wheel hub connected to the wheel shaft is made of a metal material with a certain elasticity, which enhances the shock absorption effect of the wheel and the whole vehicle when subjected to a certain impact (as shown in the figure 12).

Also, in the top view of the whole vehicle, the center wheel spacing is greater than the front and rear wheel spacing, enhancing the stability of the whole vehicle (as shown in the figure 13).
4. Motion analysis

4.1. Road running state
In the state of flat road travel, the electric push rod in the driving wheel group is in a contracted state, and the front, middle, and rear wheel groups are on the same level. The motors embedded in the axles of the four wheels of the front and rear wheel sets work synergistically and cooperate with each other to enable the planetary exploration vehicle to realize the function of walking straight in the horizontal plane.

4.2. Road running state
When turning, the motor speed of the inner wheel set is lower than that of the outer wheel set, and a speed difference is formed with the outer wheel set. The inner wheel and the ground are frictionally turned to realize the turning action of the planetary unilateral vehicle.

4.3. Active obstacle crossing state
When encountering obstacles, the rear and middle wheels brake, the front wheel motor starts, the electric push rod connected to the front wheel connecting rod extends, and the front wheel is raised (as shown in Figure 14 and 15).

Figure 12. the planetary detection wheel substructure
Figure 13. top view of the exploration vehicle

Figure 14. the exploration vehicle active obstacle crossing state
Figure 15. the front wheel lift of the exploration vehicle
After the front wheels cross the obstacles, all six wheels are started and the passive wheels float upward to adapt to the terrain (as shown in the figure 16). In the next obstacle-crossing stage, the electric push rods are extended while the rear wheels are braking, the front and middle two-wheel motors are activated, and the front wheel electric push rods are retracted (as shown in the figure 17). The various devices cooperate with each other to make the planetary exploration vehicle cross the obstacle.

![Figure 16. the floating wheels of the exploration vehicle](image1)

![Figure 17. the front and rear wheels of the planetary vehicle](image2)

5. Footnotes Project Benefits
The technical characteristics and advantages of the project are:

① Designed a brand new active obstacle-crossing mechanism with electric push rod as the main power supply.

② The vehicle adopts a two-way obstacle crossing method to solve the problem of difficult reversing.

③ The braking structure and the electric push rod structure cooperate with each other to provide a double-drive obstacle crossing method for the planetary exploration vehicle.

6. References
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