Design and Simulation of Special Hexapod Robot with Vertical Climbing Ability

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***Abstract*—This paper researched and designed the six legs of the hexapod robot, introduced the mechanical structure of the hexapod robot and the design of the legs in detail, and then performed step climbing and steep slopes climbing experiment on the MATLAB and VREP simulation platform, and the average velocity curve of the center of gravity when the fuselage moved was obtained. The experimental results show that the robot has the possibility to climb vertical walls, which has important theoretical and practical significance for further improvement and research on the hexapod robot climbing vertical walls in the future. At last, there is no doubt that this hexapod robot can be equipped with some special detectors to achieve some difficult tasks.**

Keywords*— *hexapod robot; vertical wall climbing; structural design; motion simulation

I. Introduction

As the pace of human exploration of nature continues to accelerate, the needs of various application fields for robots with autonomous mobile capabilities in complex environments are becoming wider and deeper. Among many mobile robot series, foot robots can better adapt to a variety of terrain conditions, have better stability under irregular terrain, and have the ability to isolate irregular terrain [1]. The "Made in China 2025" plan considers robots as one of the important areas in building a manufacturing power. Among them, the hexapod bionic robot has become a flexible, stable, and autonomous feature and has the ability to adapt to a variety of complex terrains. Hexapod robot has become a hot spot in mobile robot research at home and abroad [2]. For example, MIT's Mobile Telemechanical Devices Laboratory developed Attila and Hannibal [3] in the early 1990s, which was used for autonomous planetary exploration. PBJ-01 explosion-proof robots [4] and wheel-leg stair climbing robots [5] both use foot, wheel-leg composite or leg-foot composite to achieve the function of climbing obstacles [6]. The flexible movement of the hexapod robot's feet allows it to adapt to a variety of complex terrain, and the sensors and detectors carried on its body allow it to replace humans to work in some dangerous areas. Therefore, the hexapod robot has extremely high application value and wide application prospects, and can bring huge economic benefits to society.

With the efforts of researchers at home and abroad, the research on wall-climbing robots has achieved great breakthroughs [7]. At present, multiple types of wall-climbing robots with different attachment methods and motion modes have been formed. The attachment methods mainly include magnetic adsorption [8-10], negative pressure adsorption [11-13], bionic dry adhesion [14-16], and claw grasping [17-18]. Robots are mainly divided into foot-type wall climbing robots, wheel-type wall climbing robots, and crawler-type wall climbing robots according to different movement modes [19].

This article proposes an innovative design for the robot's leg structure, that is, according to the principle of biological bionics, a suction cup and a barb device are added to the robot's leg. This article mainly introduces the leg structure of the hexapod robot, and then conducts experimental simulation analysis on the robot's walking modes such as triangle gait and wave gait. Finally, the experimental results verify that the robot has the ability to climb vertical walls.

II. Design of hexapod robot

A. Leg Design

The key to whether a hexapod robot can climb on a vertical wall is whether the friction caused by the robot's contact with the wall is sufficient to support the robot. The problem of single support is easy to solve, but when it comes to the stability of the center of gravity and the emptying of the leg during the movement, we cannot only consider the friction factor. Based on research on the principles of octopus and gecko climbing, we consider using suction cups and spikes to achieve the goal.

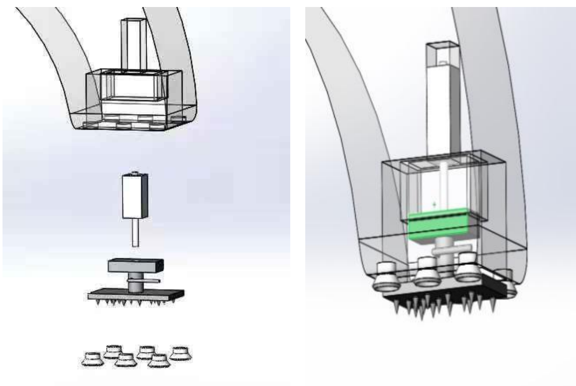

Fig. 1. Details of the internal structure of the foot

The crescent-shaped wheeled structure has been widely used in hexapod robots. Compared with the traditional single point or disc contact, this wheeled structure facilitates the high-speed movement of hexapod robots on the ground and

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climbing on vertical walls. Adjust the internal structure of the six moving feet, as shown in Fig. 1, add electromagnets, gears, suction cups and spikes in order to use a very small space to drive the movement of the entire robot. The axial connection between the leg and the body is completed by using the connection of a connecting rod. The hexapod robot can stretch out spikes with electromagnets to fit different walls. As shown in Fig. 2, when the sensor judges that the front is a rough wall, the electromagnet inside the robot's foot will control the extension of the spikes to climb the wall.

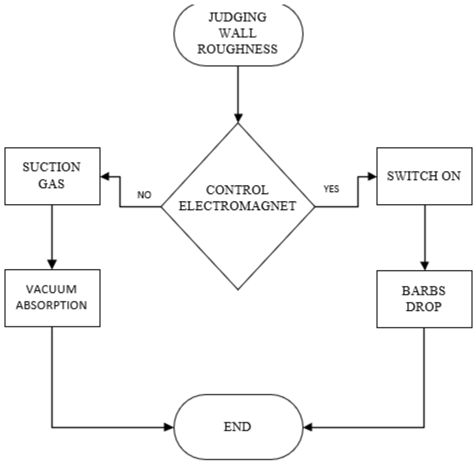

Fig. 2. How the sensor detects the wall roughness and transmits it to the foot control electromagnet or sucker

B. Design of Power System

Each leg is driven by a motor, rotates quickly at a voltage of 24V and is uniformly controlled by a STM32 motherboard. The six motors with rated voltage 24V, rated speed 439r/min, rated torque 3.5kg cm. Powered by the chosen motor, the hexapod robot can reach the highest speed as approximately 1m/s at foot robot mode. And the robot is powered by two 18650 battery set of 24V output with the size of 40mm*80mm*135mm. Excellent storage capacity and processing speed, and the cost is also relatively small, which is the reason why we give up 51 single-chip microcomputer to choose STM32. In addition to receiving information from sensors equipped by the robot, the motherboard also needs to process the external control signal received by the wireless transmission module at the same time, and give the response scheme.

C. Body design

The width of the body of the hexapod robot is 0.57m, the length is 0.90m, and the maximum width between the two wheels is 0.71m. The robot's body is divided into two parts, connected by an axis, which enables it to achieve pitching motion. This increases the robot's flexibility in a narrow, rugged environment. When encountering obstacles higher than the body, the front half of the body can pass through the obstacles without causing the fuselage to float and get stuck due to loss of friction with the ground.

D. Sensors and control systems

The front end of the hexapod robot is equipped with a vision sensor as shown in Fig.3, which is very important as the eye of the hexapod robot. Under the condition of accurately monitoring the roughness of the wall, the hexapod robot can adjust the leg structure to achieve the purpose of adapting to different walls. Of course, visual sensors can also be used as a camera, which can take photos or videos, and can also be used to explore and rescue robots with other sensors if necessary. The camera's infrared sensor and night vision function can also help locate trapped people in environments where the sight is blocked, such as smoke or darkness. Robots can be analyzed using toxic and harmful gas detectors at the location of the air composition. A pickup probe can be used to detect the sound of people walking.

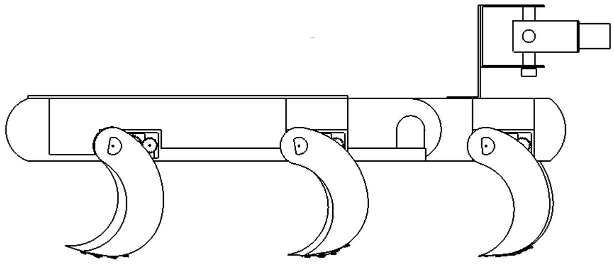

Fig. 3. Appearance of hexapod robot

III. GAIT DESIGN OF HEXAPOD ROBOT

Gait planning is essential for bionic robots. For example, if you don’t specify the cooperation between your legs and arms in advance, you will find that many people will not walk or turn around [20]. This is especially true for hexapod robots. Therefore, we need to design the gait of the hexapod robot.

A. Triangular gait

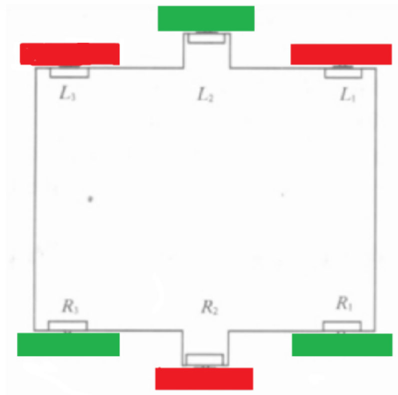

Fig. 4. Hexapod robot triangulated gait grouping

In nature, "hexapod" insects, such as cockroaches, ants, etc., generally do not move the hexapod in a straight line at the same time when walking [21]. Instead, they divide the three pairs of feet into two groups and alternately move forward with a triangular support structure. As shown in Fig. 4, L_1、L_2、L_3 indicate the front, middle, and rear feet of the left side of the body. R_1、R_2、R_3 mean the front and middle feet on the right side of the body. L_1、R_2、L_3 are one group and R_1、L_2、R_3 are the other groups, respectively, forming two triangular scaffolds. At present, most hexapod robots use an insect-like structure. When all the feet in one set of triangular supports are lifted at the same time, the three feet of the other set of triangular supports do not move, support the body, and use the feet as the fulcrum, push the body forward and cycle through each other. This way of walking allows the hexapod robot to stop anytime, anywhere, because the center of gravity always falls within the triangle bracket.

The motor that controls the rotation of the legs uses a method of non-uniform speed. If the legs of the robot are viewed from the side as an approximate semicircle, as shown in Fig. 5, in the triangle gait, the superior arc OQ segment with higher angular velocity is inferior 2.5 times the speed of the arc PQ segment.

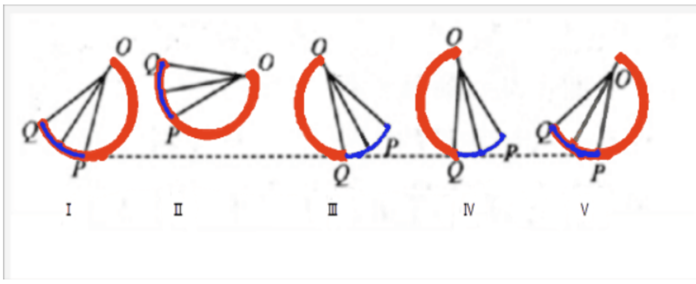

Fig. 5. Simulation of Triangle Gait

B. Wave gait

Wave gait refers to, L_1、R_1 as the first group of legs, L_2、R_2 as the second group of legs, L_3、R_3 as the third group of legs, these three groups of legs to maintain the same phase angle, at a certain speed, synchronous forward movement. The wave gait of hexapod robot is widely used, and wave gait is often used to climb slopes, steps and walls.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Construction of Hexapod Robot Simulation Environment

In SOLIDWORKS software, the hexapod robot fuselage and the details of each part are drawn, imported into VREP software for scene simulation. In addition, combined with the writing of MATLAB program and further simulation experiments of VREP software, this paper studies the possibility of hexapod robot climbing walls, and simulated various walking scenes of hexapod robots in VREP simulation experiments, such as triangular gait walking, wave gait walking, wave gait climbing steps and slopes, and two kinds of vertical wall.

B. Analysis of gait simulation results

In the VREP software, the triangle gait of the robot is simulated, and it is found that the ratio of the angular velocity of the superior arc OQ segment to the inferior arc PQ segment determines the speed of the robot's body movement and the stability of the body. The smoothness of the fuselage can be intuitively measured by measuring the average speed of the fuselage in the vertical direction during the walking of the hexapod robot, as shown in Fig.6. The larger the curve fluctuates, the less stable the body is during walking.

TABLE I. RESULTS OF TRIANGLE GAIT EXPERIMENT

a_n	k	Body degree of stability
2.00	2.63	unstable
2.25	3.79	Relatively stable
2.50	5.84	stable
2.75	10.53	unstable

Where, a_n refers to the ratio of the optimal arc OQ segment to the angular velocity of the inferior arc PQ segment. k refers to the angular velocity r/min of the robot's leg movement.

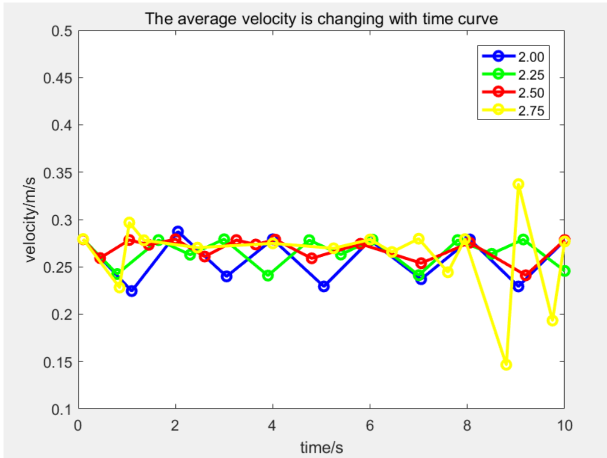

Fig. 6. Curve of average speed of fuselage under different conditions

Through the analysis of the experimental results, it can be seen that the center of gravity is stable when the ratio of the angular velocity of the superior arc OQ section to the inferior arc PQ section is 2.50.

C. Analysis of Unstructured Terrain Simulation Results

The robot's obstacle-crossing behavior is actually the process of robot adapting to unstructured terrain, such as slopes, steps, etc. The simulation results show that the robot can climb the vertical wall of the hexapod robot. The experimental results of the hexapod robot climbing the steps and the 40 °slope are analyzed in detail below.

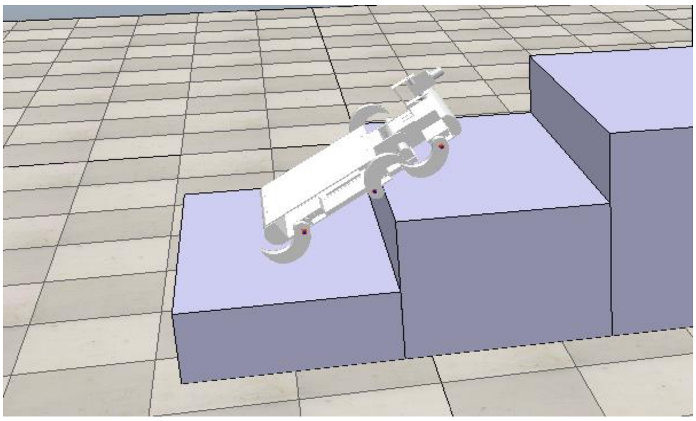

Fig. 7. Hexapod robot climbing steps in VREP simulation environment

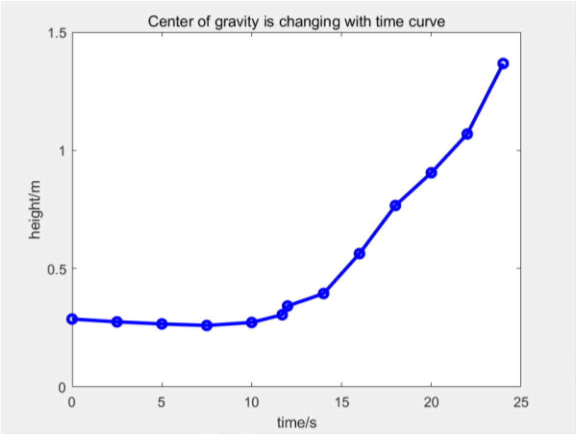

Fig. 8. Time-dependent curves of the climbing center of gravity in the vertical direction

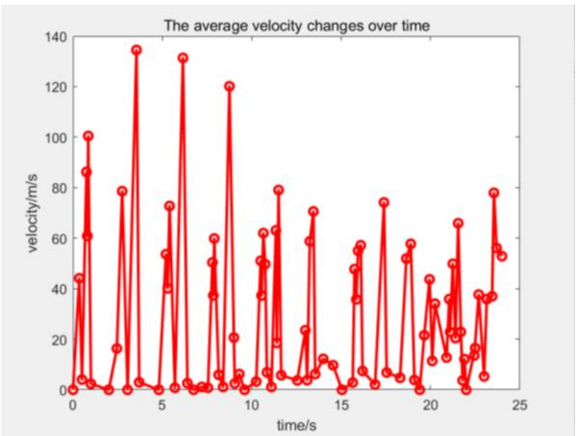

Fig. 9. Instantaneous velocity curve for climbing slopes

Fig. 7 shows the experimental process when the hexapod robot steps over a 4th step with a height of 300.0mm and a width of 800.0mm. Fig. 8 and Fig. 9 show the experimental process when the robot climbs a slope with a slope of 40 °and a slope length of 5000.0mm. It can be known from the results of the different unstructured terrain experiments that the present hexapod robot has the possibility of climbing a vertical wall.

V. CONCLUSIONS

Through innovative design of the structure of the body and legs of the hexapod robot, a model was made in the SOLIDWORKS software. Through several joint simulation experiments in MATLAB and VREP, the hexapod robot can flexibly and reliably complete various basic operations, such as walking on flat ground, climbing steps or steep slopes. The robot is fully capable of climbing up a vertical wall.

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