Structural Performance Analysis of Wall Climbing Robot

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Abstract. With the development of artificial intelligence technology, robotics technology has become more and more mature. Ground walking robots not only develop rapidly, but also have been applied in actual production and life. However, the development of wall climbing robot technology is still in the laboratory research and small-scale application. We live in a world where progress is continuing. Large-scale buildings, bridges and ships are becoming more and more common. In these places, it is inevitable to involve the construction, maintenance and clarity of high-rise buildings and ships. In the case of dangerous and inefficient manpower work, the application of wall climbing robots can play a very good role. Therefore, the development of wall climbing robots is of vital importance both now and in the future. Starting from the performance characteristics of wall climbing robot, this paper studies and summarizes the moving mode, control mode, conditions to be satisfied and various adsorption forms of wall climbing robot, and introduces the basic research situation in the field of wall climbing robot.

1. Introduction

With the progress of technology, people pursue high efficiency and safety. The trend of using robots to replace manpower for production has become more and more obvious. The effect of some heavy and dangerous fields is more significant. With the rapid development of China's construction industry, some problems arise. The danger coefficient of high altitude operation is very high and the efficiency of manpower is low. If the wall climbing robot can be fully applied in this field, these problems can be well solved. It can be used in glass cleaning, wall spraying, transportation of building materials and construction monitoring, etc. The work efficiency and safety will be further improved. It can also be used in the construction and cleaning of large ships. Wall climbing robots have experienced many years of development, from simple pressure adsorption, magnetic adsorption, to more complex bionic adsorption, electrostatic adsorption forms, and until today, they are divided into wall climbing robots relying on rigid actuators and soft wall climbing robots based on flexible muscular strong actuators. These wall climbing robots have their own characteristics, and the emergence of software wall...
climbing robots has opened up a new research idea. Moreover, in order to adapt to different working environments and purposes, the moving mode, control mode, driving mechanism of wall climbing robot show diversity, and the necessary conditions for a practical wall climbing robot are gradually summarized. Laboratory research on wall climbing robots has been relatively mature, and each specific kind of wall climbing robots can also be applied in a certain field. Some wall climbing robots are used in real life. The future development and application prospect of wall climbing robots is very broad.

2. Moving Mode of Wall Climbing Robot
Among the wall climbing robots that have been developed, wheeled, Crawler type and multi-legged moving modes are widely used. They have their own advantages and disadvantages in stability, flexibility, weight, speed and safety. Firstly, wheeled wall climbing robots generally use four-wheel moving mode. Because the contact area between the tire and the ground is small, in order to provide the friction force needed to propel it, it needs to provide a greater force to press it to the wall, so the energy consumption of the adsorption mode is larger. But its turn is very flexible, its running speed is faster and its reliability is higher. Secondly, the crawler wall climbing robot is powered by the motor to the active axle. The active axle drives the crawler movement to realize the moving of the robot. The contact area between the crawler and the wall is large and the adsorption force can be effectively utilized. Therefore, the crawler wall climbing robot has strong obstacle surmounting ability, self-locking ability, safety and reliability. However, the crawler wall climbing robot runs slowly. It makes the left and right crawlers run at different speeds through gearboxes, thus realizing steering, which is relatively less flexible and has poor steering ability. [1]Finally, the moving of the multi-legged wall climbing robot is realized by providing the adsorption capacity of each leg and planning the movement of each leg. Typical wall climbing robots are negative pressure type, bionic type (rigid hair adsorption, hook-claw type, liquid adhesion type), wall climbing robot and software wall climbing robot with electric adhesion. Multi-legged wall climbing robots generally divide their feet into two groups: one group keeps adsorbing, the other group moves forward at a certain angle through the steering gear. When the rotation angles of the two groups of feet are different, the steering function can be realized. Because the multi-legged wall climbing robot moves slowly by controlling the rotation angle, and each leg has an adsorption device. The moving needs to control the adsorption and rotation of the legs, which makes its structure more complex. [2]But the complex control of multi-legged wall climbing robot makes it more flexible and can move between two vertical planes. The movement with it requires the discontinuous adsorption of each foot to be reasonably arranged, so its adsorption stability is insufficient. Soft wall climbing robot can achieve intermittent adsorption for front and rear feet by electro-adsorption, and move forward through dielectric elastomer actuator expansion. Under different voltage, the speed of adsorption ability of the soft wall climbing robot has a certain change.

3. Control Mode of Wall Climbing Robot
There are three commonly used control modes of wall climbing robot, which are single chip computer control system, PLC control system and DSP chip processing system. Single chip computer is the simplest one. It occupies less space, has higher integration, has better control ability and expansion ability, data processing speed is fast and has high accuracy.[3] It is a very safe and stable control method, so it has been widely used in actual production. The digitalization and intellectualization realized by single-chip computer effectively improves the traditional electronic circuit and digital circuit. It has powerful functions and outstanding comprehensive performance. The PLC control system uses general software and hardware, and has no specific operating station, so the cost is low. [4]The PLC controller can receive thousands of I/O points at most. It is more practical in the system of wall climbing robot, which is equipped with interlocking devices and fewer loops. The PLC controller is similar to a strengthened single chip computer, which processes the input and output signals to a certain extent, and obtains more accurate data processing results. It has good anti-interference. DSP chip is also called digital signal processor. [5]It has the characteristics of fast data processing speed,
larger processing capacity, and image processing function. In signal processing, it is much faster and more powerful than single chip processor.

4. Requirements for Wall Climbing Robots
Wall climbing robots are generally used in detection, maintenance and cleaning in practical applications. In order to meet the needs of practical applications, some of their performances have certain requirements, such as load capacity, stability, safety, practicability, flexibility and running speed. [6] Running speed and flexibility are two important parameters of wall climbing robot. The efficiency of wall climbing robot is directly related to its speed. Some jobs require sensors to continuously detect wall defects. Others require a wall climbing robot to rotate 360 degrees around the wall to find a suitable location, to run along a specific trajectory, and to have a certain obstacle-surmounting ability. [7] These are all related to flexibility and speed. Carrier capacity involves the use of wall climbing robots. Some application scenarios require robots to bring cameras and sensors. For example, a simple surface detection requires wall climbing robots to carry at least 10g of equipment. The carrying capacity of wall climbing robots is directly related to its shape, self-weight and adsorption capacity, and also needs to consider energy consumption.[8] Stability and safety are determined by robustness to some extent. Robustness is an important factor to be taken into account when a wall climbing robot is put into use. Errors in a task directly affect whether it is suitable for use. The stability and safety test includes the robustness of hardware, whether the control system can process data accurately, control the movement of the robot, the processing ability and self-repair ability when encountering complex situations, etc. [9] The last practicability is also a very important index. It adjusts the load according to the specific task. When it encounters different problems, it deals with the diversity of problems, has stronger maneuverability and energy consumption control. [10] All these require the wall climbing robot to have more reasonable maneuverability.

5. Various Types of Wall Climbing Robots

5.1. Pressure Adsorption Wall Climbing Robot
Pressure adsorption wall climbing robots are divided into negative pressure wall climbing robots and positive pressure wall climbing robots. Negative pressure wall climbing robots draw air from suckers to form a negative pressure environment, and use atmospheric pressure to provide pressure to fix the car on the plane. It can be divided into two forms to form negative pressure. One is to use vacuum pump to form a vacuum environment in the sucker, i.e. the vacuum wall climbing robot. It has high requirements for the plane. [11] It is easy to leak pressure on the unsmooth plane or the slit plane, resulting in the formation of a vacuum environment, cannot work normally and is prone to dangerous situations. Another way to form negative pressure is to use high-speed runoff centrifugal fan, which forms a negative pressure environment with a certain pressure difference by eliminating air. It does not require the right vacuum environment. There are certain gaps between the suction cup and the wall, so the requirements on the wall are not so harsh and can be applied to more environments. However, the corresponding runoff centrifugal fan wall climbing robot also has some disadvantages, such as large energy consumption and noise, and when passing through the wall with a larger gap, the pressure changes more and it is easy to fall off. The two methods of forming negative pressure have different moving modes. Vacuum adsorption wall climbing robot adopts multi-legged moving mode. The foot needs to be adsorbed intermittently during moving. The key of adsorbing movement is to control the movement sequence of foot. Runoff centrifugal fan wall climbing robot generally uses wheeled or caterpillar mode of moving, the adsorption capacity has no direct relationship with its movement, its movement is achieved by controlling the speed of tires.
The barotropic wall climbing robot provides pressure through the fan, which enables the wall climbing robot to stand on the wall. The typical one is Stanford climbing flight maneuvering platform, SCAMP, which has mature control system. In motion, its four-axis vehicle enables it to land on a vertical plane, and through its long tail with an accelerator, the robot can land steadily on the plane. When it slips on the plane, it can also be pushed to the vertical plane or adjusted to flight state by the largest rotor of the aircraft. It also uses a light and long antennal foot, which can run over a long distance on the plane. A hook claw is installed in front of the foot to firmly grasp the wall and ensure its stability on the plane. Another kind of barotropic wall climbing robot provides oblique thrust through the culvert fan. The thrust provided by the traditional wall climbing robot has an angle with the plane, that is, to provide pressure to press the robot on the wall, while providing an upward thrust, which reduces the friction required by the robot running on the wall and improves the utilization of energy.

5.2. Magnetic Adsorption Wall Climbing Robot
Because many buildings are iron frame structures, and large ships can use magnetic adsorption wall climbing robots. The magnetic adsorption wall climbing robot is designed by using the magnet's ability to attach to the magnetic wall. It can be used on the iron plane and can be responsible for cleaning, inspecting and repairing the outer wall of large ships. The moving modes adopted are magnetic foot, magnetic wheel and caterpillar. The magnetic foot uses solenoid foot to provide adsorptive force. Because the movement needs to adjust the magnetic force, it is more complex, and the stability and flexibility are not very good. [12] The magnet wheel is used to absorb the wall. Because the contact area between tire and wall is small, the utilization ratio of magnetic force is not very high and the load capacity is relatively poor, but its flexibility is better. The crawler type magnetic adsorption wall climbing robot has a larger wall area and better load capacity, but its flexibility is relatively poor.

5.3. Bionic Wall Climbing Robots
The bionic wall climbing robot is developed by studying the climbing ways of animals. It includes many ways of climbing and adsorbing, such as bristle adsorption, claw climbing and mucus adhesion. Rigid hair adsorption is inspired by studying the way gecko climbs the wall. By making burrs like the bristles on the soles of gecko's feet and using van der Waals force between molecules, the adsorption can be achieved. But because these bristles are very fine, the disc size at the end of the bristles is micron, so they are in the laboratory stage. The sticky wall climbing robot is developed by researching climbing methods like Oriental salamander. It fits the wall with the sole of foot, and then secretes sticky fluid to adhere to the wall. However, its running speed is slow and its practicability is not strong. The hook-claw wall climbing robot is developed by observing the way spiders climb the wall. It helps
the wall climbing robot to climb on the wall by installing sharp hooks and claws in front of its feet. When moving, the hooks and claws grasp the rough part of the wall and provide the robot's attachment force. It is suitable for climbing on the rough wall. The Stanford climbing flight platform mentioned earlier uses the hook claws to climb on the rough wall. Climbing the wall. It is more suitable for use in conjunction with other wall climbing methods, such as a composite wall climbing robot with hook and claw climbing and vacuum adsorption.

5.4. Software Wall Climbing Robot
Different from wall climbing robots relying on rigid actuators, wall climbing robots rely on muscle-like actuators to achieve crawling. Existing wall climbing robots use pneumatic actuators, shape memory alloys and dielectric elastic actuators as crawling actuators. But they are not perfect enough. Like the pneumatic actuator tethered software robot developed in recent years, it can crawl in a vertical pipeline, but cannot crawl in plane. The difficulty in designing a wall climbing robot is to design the adhesion mechanism and the executing mechanism, and to plan and adjust the operation of the adhesion component and the executing component so as to achieve the effect of stable moving on the wall.

Dr. Liu Xinyu of the University of Toronto, Canada, has studied a paper-based wall climbing robot, which can crawl on the walls of various materials using electrostatic adsorption. It consists of paper and shape memory alloy. The paper built-in electrodes can produce greater adhesion by cooperating with paper-based robots and using commercial high-voltage frequency converters. With the activated shape memory alloy, repetitive reciprocating drive can be realized, and the crawling speed can reach 1 mm/s.

The soft wall climbing robot developed by Professor Zhu Xiangyang of Shanghai Jiaotong University and his team uses a new electroplating attachment technology. It can crawl on almost all walls at a very fast speed. The climbing speed can reach 63.43 mm/s, the running speed on the horizontal plane can reach 88.46 mm/s, and it can turn at a speed of 62.79 degrees per second. It can carry a certain amount of equipment and has a good moving effect. The flexible wall climbing robot is composed of a dielectric elastomer as its operating component and two electro-adhesive feet as its adsorbing mechanism. By applying a certain frequency of voltage to them, it achieves a synchronous human deformation moving effect. As the main component of the robot, dielectric elastic actuator consists of dielectric elastic film, acrylic frame and two compatible grease electrodes. When moving, the dielectric elastic actuator, due to the stretching and bending of the elastic film, makes the actuator expand continuously by applying voltage rise and fall, and cooperates with the intermittent adhesion of the electro-adhesive foot to achieve the effect of moving forward. Another key component of the electro-bonding foot is composed of two polyimide layers and a copper electrode layer. [13]The electro-bonding foot is made of cross-fingered concentric electrodes. When voltage is applied to the electro-bonding foot, the corresponding foot can adhere to the wall, and the dielectric elastic actuator can achieve smooth creeping effect.

6. Conclusion
After the development of wall climbing robots, from the simple pressure-type wall climbing robots, wind-driven wall climbing robots and magnetic wall climbing robots to the more complex bionic wall climbing robots, to the research of wall climbing robots based on electrical adsorption, the research of wall climbing robots has become more and more mature, the adsorption methods used are more and more mature, and the wall climbing effect is better and better. The maturity of technology makes it more widely used, not only in wall cleaning, maintenance and testing, but also in monitoring and material transportation. The future prospects of wall climbing robots are very broad. Researchers are exploring new research directions regardless of the direction, and research directions are also blooming, attracting more talents to join the industry and achieving more amazing results. Nowadays, the operation and use of wall climbing robots have become more natural and smooth, and the adsorption capacity and load capacity have been greatly improved. Researchers are gradually
overcoming the difficulties faced by wall climbing robots in the use process. It is believed that in the near future, more ingenious adsorption methods will be found, the load capacity will be stronger, more flexible, environmental constraints will be overcome, ease of use and security will be unprecedented guarantees, wall climbing robot technology will enter people's lives.

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