Design and Application of Intelligent Cleaning Robot Walking System for High-altitude Glass Curtain Wall

Jian-xun DENG\textsuperscript{1,*}, Ying-hang DENG\textsuperscript{2} and Ding-cheng WANG\textsuperscript{3}

\textsuperscript{1,2}School of Architecture and Civil Engineering, Xiamen University, Xiamen, China
\textsuperscript{3}Hua Wei Internet of Things Technology Co., Ltd. Xiamen, China
\*Corresponding author

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Abstract. In order to meet the needs of high-altitude glass curtain wall cleaning, a multi-suction disc sliding high-altitude curtain wall intelligent cleaning robot was designed. The cleaning robot sliding chuck, obstacle and rotation ability, walking circuit and mobile working principle were designed and studied. After three generations of walking system optimization design research, from belt and suction cup walking system design to gas rod and suction cup walking system design, to multi-suction tray sliding self-climbing obstacle system, from adsorption performance, obstacle resistance, mobility and other aspects optimized design. Finally, the high-altitude curtain wall intelligent cleaning robot with better performance and could be adapted to the cleaning operation under different conditions was obtained, and was put into the market for practical application test, and obtained better application effect.

Introduction

The glass curtain wall is widely used in high-rise buildings because of its advantages of good lighting, good moisture-proof and moisture-proof performance, and practical appearance\textsuperscript{[1]}. Due to the wind and sun all year round, the glass curtain wall needs to be cleaned and maintained regularly. Because of the high altitude work, the traditional manual cleaning method is inefficient and dangerous. Therefore, the use of wall-climbing robots instead of manual cleaning of curtain wall cleaning tasks has become a hot topic at home and abroad\textsuperscript{[2]}. The development of artificial intelligence makes it possible for robots to replace dangerous work for people. The construction industry is one of the lowest mechanized industries, and the emergence of robots will be a trend in its future development.

The glass curtain wall cleaning robot was first developed by the Russian Academy of Mechanical Sciences. It is a simple single suction cup structure climbing wall. The suction cup is composed of moving mechanism, cleaning operation device and control unit\textsuperscript{[3]}. It must be able to move on the glass surface while completing the cleaning function. It must have three functions of adsorption, movement and cleaning. In addition, it must have a certain communication system to facilitate remote control.

In the initial stage of the development of the glass curtain wall cleaning robot, Sato Doto from Japan's Rihui Co., Ltd. invented a wall crawling robot in the form of using two suction cups. This robot adopts a vacuum suction cup. The airtight area between the wall surface and the vacuum suction cup has a good sealing effect, which can prevent the pressure of the suction cup from leaking when the robot moves\textsuperscript{[4]}. J. Savall and others designed a vacuum-adsorption foot-type wall-climbing robot for the detection of hazardous environments in nuclear power plants. This kind of robot provides adsorption force by four vacuum chucks\textsuperscript{[5]}. Toshio Fukuda and others developed a vacuum-adsorbing crawler-type wall-climbing robot with a vacuum chuck mounted on the track. The air valve in the vacuum chuck uses a mechanical valve to ensure the reliability of the suction cup\textsuperscript{[6]}.
At present, cleaning technology can be divided into three categories: physical cleaning, chemical cleaning and microbial cleaning according to the difference of working principle[7]. Among them, chemical cleaning and microbial cleaning have not been widely used because of the use cost and environmental factors, and in view of the operation cost and the ease of operation, only the mechanical cleaning method in the physical cleaning method has been popularized. The adsorption function refers to the ability of the robot to be parked on the glass surface by some driving force without falling down by gravity. South Korea's Gyeonggi University scholars Kim, Taegyun and Kim, Jongwon proposed that the curtain wall cleaning robot is important to maintain the contact force between the robot cleaning unit and various types of walls to ensure good cleaning performance.

**Intelligent Cleaning Robot Walking System Design and Optimization**

**Belt and Suction Cup Walking Type Intelligent Cleaning Robot**

This kind of robot mainly consists of a vacuum suction adsorption system, a moving belt, a water spray system and a cleansing device. The belt and suction cup walking system is used to design a high-altitude curtain wall cleaning robot. The robot can ensure the adsorption capacity between the glass curtain wall and the glass curtain wall to maintain the adsorption capacity in the work, and realize the movement ability in the curtain wall cleaning work through the belt.

![Figure 1. Belt and suction cup walking type intelligent cleaning robot.](image)

The advantages of the robot with belt and suction cup walking system are as follows: The mechanism design is simple, easy to install, manufacture and repair. The walking system is simple in design and the walking system is easy to adjust. The walking stroke of the walking system can be adjusted according to the length of the belt, which is simple and convenient. The suction is large and the robot is stable in adsorption.

This is the first generation of intelligent cleaning robot developed by our research group. Through the actual curtain wall cleaning test, due to this simple design system, this type of robot also has certain shortcomings and improvements. Limited by the walking system of the belt suction cup, this kind of robot can only walk in the direction of the belt, can only move forward or backward, cannot move freely in multiple directions, and encounters the brighter frame and the dark frame of the curtain wall. The suction cup is easy to press the seam during work, resulting in insufficient adsorption capacity and the risk of falling. The vertical travel of the belt limits the volume of the robot. The larger the stroke, the larger the volume of the robot. The normal walking capacity of the belt can only withstand a maximum of 25kg of heavy objects, which has a greater restriction on the development of robots. Moreover, this robot work needs to be equipped with an air compressor to provide adsorption capacity, which is inconvenient to use.

Due to the simple mechanism design of the belt, the robot also has a problem of low fault tolerance for robot processing and operation. If there is an error in machining, the robot will have a large deviation after a period of normal operation. During the performance test, the robot slipped several times during the travel of 5 meters to 10 meters due to machining errors, causing the robot to fall.
The biggest problem with this kind of robot is the defect of walking ability and carrying capacity, and the simple mechanism design obviously cannot bring more convenience for practical application. In response to the above problems, the research team also carried out a series of improvements to the robot.

**Gas Rod and Suction Cup Walking Type Intelligent Cleaning Robot**

This kind of robot mainly improves the walking ability and carrying capacity of the robot, and is mainly composed of a combined suction cup vacuum suction system, a gas rod, a water spray system and a cleansing device. Compared to previous designs, this robot uses a combination suction cup to provide excellent adsorption capacity and is relatively simple to design. The movement through the gas rod is also more reliable, and the stroke can be adjusted according to the length of the gas rod, which is simple and convenient. In terms of carrying capacity, the carrying capacity of the travel system equipped with gas rods is significantly better than that of the travel system equipped with belts. This walking system can withstand more than 100kg of heavy objects. For the design of robot mechanism, it avoids the limitation of load restriction and design. The space is more complete.

![Figure 2. Air rod and suction cup walking intelligent cleaning robot.](image)

The robots of this generation focus on solving the problems of carrying capacity and walking ability, and a series of problems existed before. This kind of robot walking system still relies on the air compressor to operate, which brings inconvenience in practical use. Due to the limitations of the pneumatic rod travel system, the robot can only walk in the vertical direction of the gas rod and cannot move in the horizontal direction. The stroke of the gas rod limits the volume of the robot. The larger the stroke, the longer the length of the required gas rod, the larger the volume of the robot, and the limitation on the design of the robot mechanism. In addition, the processing and operation requirements of the robot are also quite high, and there are errors, and the robot is prone to route deviation during long-term work.

**Multi-suction Tray Self-climbing Obstacle-free Intelligent Cleaning Robot**

This kind of robot mainly consists of multi-suction disc vacuum suction, moving wheel, water spray system and cleansing device. For the robot cannot turn, the direction of travel is single, easy to offset the track drop and other issues, and improved the design of such a good robot.

![Figure 3. Multi-suction tray self-climbing obstacle-obstacle system robot.](image)

This robot has a lightweight design and highly automated work capabilities. The robot can walk on the glass surface and can walk freely on the glass surface, go up, down, left, and right, turning 360 degrees. It is more convenient to use without using an air compressor. Its safety performance is reliable, it can be firmly adsorbed on the curtain wall surface, and can withstand 30kg gravity and...
80kg vertical force in addition to the gravity of the robot. The robot can realize automatic correction and automatic over-canting, which can reach 50*70mm obstacles. The robot has higher technical requirements for suction cups and sliding plates, and the production cost is higher.

Multi-suction Tray Self-climbing Obstacle System Glass Curtain Wall Cleaning Robot Walking System Mechanism Design

Sliding Suction Cup Design

The glass curtain wall cleaning robot is mainly composed of a multi-suction cups negative pressure adsorption, movable wheels, water spray system and a cleansing device.

![Figure 4. Structure of Multi-suction cups sliding cleaning robot for glass curtain wall.](image)

The sliding suction cup is composed of an electric fan and a sliding sealing device. It has the advantages of being insensitive to gas leakage, relatively simple structure and eliminating the need for large air pump equipment, and is suitable for working on a flat wall surface. When the driving motor runs and the suction cups are close to the wall surface, under the action of the sealing device, a negative pressure is generated in the suction cup, and the robot is attracted to the wall surface, thereby maintaining the pressure of the squeegee against the wall surface and the squeezing force against the wall surface when the rotating brush rotates at a high speed.

Special attention should be paid to the design of the suction force value, which should not be too large or too small. Due to the relative sliding between the sliding suction cup and the wall surface, the greater the adsorption force, the increase of the positive pressure. The sliding frictional resistance of the sliding suction cup contacting sealing surface and the rolling friction of the wheel which are overcome during the movement of the wall robot are increased. It is possible that the wheeled wall robot cannot move, thus it’s necessary to increase the driving power, otherwise it is possible to cause the motor to be overloaded or burnt. However, if the adsorption force is too small, the stable adsorption of the wheeled wall robot during the movement cannot be guaranteed due to the influence of the gravity of the robot itself, or although the wall surface adsorption can be maintained, but due to small deformation of the sealing device, the driving wheel cannot be sufficiently contacted to the wall surface or even suspended, then it cannot obtain sufficient wall traction.

Obstacle-crossing and Rotation Ability Design

Since the curtain wall has exposed frames and hidden frames, the cleaning robot needs to have a good ability to cross obstacles when walking on the curtain wall. The design idea originated from the cooperation of two basic modules. The two basic modules are fixed on the same platform, driven by push rods and guide rails, so that they can move up and down perpendicular to the platform to achieve the goal of crossing obstacles. When the lower module is adsorbed on the glass curtain wall, the lower push rod is pushed out, and the upper module is suspended, and the whole robot can be driven up and down by the dual motor of the lower module. Similarly, when the upper module is adsorbed on the glass curtain wall, the upper push rod is pushed out, and the lower
module is suspended, and the entire robot can be driven up and down by the dual motor of the upper module. In order to reduce the blind spot of the curtain wall cleaning, the robot needs to increase its own rotation function to stop at any angle, and realize a variety of cleaning devices, so that it can clean any angle, reducing the blind spot of the curtain wall cleaning. According to the calculation and experiment, when only the upper module or the lower module is suspended, the cleaning robot has a sufficient adsorption capacity to maintain stable adsorption on the glass curtain wall.

**Moving Working Principle of Curtain Wall Cleaning Robot**

The robot is mainly composed of eight suction cups with vacuum suction, walking device, high pressure spray cleaning device, ducted fan and cleaning mechanism. The suction cup system consists of eight single-sided open arc-shaped suction cups, an elliptical negative pressure chamber and a sealing device. When the ducted fan is running and the eight suction cups are close to the wall surface, under the action of the sealing device, a negative pressure is generated in the suction cup, and the robot is attracted to the wall surface, thereby resisting the pressure on the wall surface when the cleaning device scrapes the wall surface. When the robot moves from top to bottom, the suction force is not as large as possible because of the relative sliding between the suction cup and the wall surface. If the adsorption force is too small, when the suction cup encounters excessive leakage of the wall concave gas, the robot cannot reliably adsorb to the wall surface, resulting in the wall surface adaptability being deteriorated. In addition, during the operation process, if the cleaning pressure acting on the wall surface is too small, the cleaning quality is difficult to be guaranteed. However, if the cleaning pressure is too large, the reaction force of the wall facing the robot is also large, and the adsorption force is increased, otherwise the robot is liable to fall.

**Conclusion**

Aiming at the cleaning problem caused by the high-rise building glass curtain wall, a self-climbing obstacle-free high-altitude curtain wall intelligent cleaning robot was developed, and the following conclusions were drawn through the testing of the robot: (1) According to the structural characteristics of the existing cleaning robots, combined with the functional design experience of the two generations of robot movement, cleaning, obstacles-crossing and adsorption, the multi-suction tray self-climbing obstacle system glass curtain wall cleaning robot while adsorbing while walking The structural design ensures the flexibility of walking, enabling the robot to adapt to multi-height floor construction; (2) This new cleaning robot has the characteristics of convenient operation, flexibility, obstacles and high cleaning efficiency, which provides reference value for the development of such robots in the future; (3) The adsorption force of this new cleaning robot can guarantee the normal working demand, and has certain dirt resistance performance, can adapt to long-term outdoor work, and has high practicality. 

The first two generations of products have many defects, which have caused the products to be unable to be introduced to the market. Although the third generation products have higher requirements for suction cups and sliding plates, but they have mastered the core technology of suction cups and sliding plates, so now they have successfully pushed this generation of products to the market. In China, it successfully operated in Shenzhen, Xiamen, Quanzhou, Shanghai and Hangzhou, and cleaned more than 20 dozens of Xiamen Jordan Haixi Center, Guojin Square, Lingyun Jade, Jinjiang Real Home, Quanzhou World City and Shanghai Zhongjun Square. project. In foreign countries, there are customers in Singapore, Saudi Arabia, Qatar, the United States, Canada and other countries.

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