Design of the Curtain Wall Cleaning Robot

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Abstract. The curtain wall cleaning robot suitable for special-shaped wall structure of buildings is designed, and the mechanical structure design and control system design of the curtain wall cleaning robot is completed in the paper. The curtain wall cleaning robot is composed of two parts with the same structure. The hinge mechanism is used to realize the turning action of irregular wall. The suction and movement of the cleaning robot are realized by vacuum adsorption of the sucker. And the motor controlled the rotation of the roller brush. The screw guide rail drives the roller brush up and down to realize cleaning. Based on the mechanical structure design, the control system of curtain wall cleaning robot is designed. And PLC control system is used to control the sequence of action of curtain wall cleaning robot.

1. Introduction
At present, the cleaning of most glass curtain walls in China relies on "spiderman" to complete the cleaning at high altitude. The working environment of workers is very bad, and there are certain safety risks. Cleaning the surface of a building is time-consuming, inefficient and expensive. Therefore, it is necessary to design an efficient and convenient curtain wall cleaning robot to replace manual work. More and more special-shaped buildings have been built, and the shape of such buildings is not a single plane, all with a certain tilt Angle, which requires the cleaning robot to have more functions. In China, the research on wall mobile robot started very late, but the development speed is very fast. Since 1998, special robot research office of institute of robotics, Harbin Institute of Technology has taken the lead in the research of wall-climbing robots with the support of the state[1]. It has made many positive and meaningful explorations and attempts. The negative pressure adsorption and magnetic adhesion two series of five kinds of wall crawling robot have been successfully designed and manufactured. There are two kinds of cleaning climbing robot: single sucker, double wheel and double crawler, which can clean ceramic tile and glass wall. In foreign countries, the development of curtain wall cleaning robot is slightly earlier, BVE company of Japan has successfully developed a fixed-track automatic window cleaning robot, which mainly relies on the track and cable lifting system installed on the roof of the building to align the window cleaning machine with the window, and then the robot moves vertically up and down the guide groove fixed on the surface of the building for automatic cleaning. BVE company of Japan has successfully developed a fixed-track automatic window cleaning robot, which mainly relies on the track and cable lifting system installed on the roof of the building to align the window cleaning machine with the window, and then the robot moves vertically up and down the guide groove fixed on the surface of the building for automatic cleaning. It's highly automated and efficient, and of course expensive, and it requires Windows cleaning systems to be taken into account at the beginning of a building's design, and tracks to be laid. Otherwise, it cannot adapt to the stepped shape of the wall and Windows, nor is it suitable for the already built
buildings[2]. So not only the scope of use and efficiency of the equipment is severely restricted, but also to the building itself increased a huge cost. Therefore, this paper innovatively designs a curtain wall cleaning robot suitable for special-shaped wall structure of the building, and the hinge mechanism realizes the reversal of special-shaped wall.

2. Overall Design of Curtain Wall Cleaning Robot

2.1. Selection of Various Parts of the Curtain Wall Cleaning Robot

The curtain wall cleaning robot can be divided into five parts: the cleaning part, the adsorption part, the moving part, the turning part and the shell. Morphological matrix was established for the type selection of each mechanism, as shown in Table 1.

| Cleaning device | Disc brush | Roller brush | Strip brush |
|-----------------|------------|--------------|-------------|
| Adsorption device | Negative pressure adsorption | Magnetic adsorption | Thrust adsorption |
| Moving device   | wheel      | caterpillar  | Foot type   |

(1) Cleaning part of the design: such as the disk brush through the high-speed rotation to achieve the purpose of cleaning, which is fast and convenient, but because of the way of cleaning, some corners can not be cleaned. The cleaning method of the brush is to achieve the cleaning purpose by moving up and down the brush, with low efficiency and weak cleaning degree. The rolling brush cleans a range through the rotation of the rolling brush itself, and then drives the rolling brush up and down through the screw rod for cleaning. And the cleaning effect is better[3].

(2) Adsorption part design: the working principle of magnetic adsorption is to make the curtain wall cleaning robot body adsorbed on the wall by magnetic force, and then the curtain wall cleaning robot starts to work. Magnetic adsorption requires that the problem of conducting materials be considered in advance when building a building. The working principle of wind thrust adsorption is to generate an opposite force through the fan, so that the robot is adsorbed on the wall, the greater the thrust required, accompanied by noise. At present, most designs adopt negative pressure adsorption. Sliding seal negative pressure sucker is used here to ensure sealing by controlling the gas pressure in the sealing ring and adopting inflatable rubber sealing skirt edge. Sealing ring can better fill the gap between the sucker and the wall surface, so that the sucker and the wall close together. Therefore, a certain sealing environment is formed in the cavity of the sucker, which is able to adapt to the environment where the wall surface is not completely flat.

(3) Design of moving part: footwork imitates the biological movement method, but the movement speed is slower, the structure is more complex, and the cleaning efficiency is lower. The wheel movement efficiency is higher, but because of the wheel structure question, causes the adsorption to become difficult, has the security hidden trouble. Track moving speed is fast, multiple suckers ensure the safety of sucker adsorption, more appropriate. The movement method used here is for the purpose of moving through the rotation of the triple sucker foot[4].

(4) Flip mechanism design: when facing the non-planar wall, one end of the curtain wall cleaning robot can be raised to climb up the special-shaped wall. For this kind of turnover movement, it can be analogous to the opening and closing of a door, and the two sides are connected by a hinge. In conclusion, the curtain wall cleaning structure is mainly cleaned by rolling brush, and the screw rod drives the roller to move up and down to achieve the purpose of cleaning. The purpose of movement is achieved by negative pressure adsorption of sliding seal and rotation of sucker foot.
2.2. Working Principle of Curtain Wall Cleaning Robot

Curtain wall cleaning robot is driven by motor, sliding seal adsorption to complete the adsorption movement. Firstly, the pneumatic cylinder is started, and the robot is placed on the glass wall for solid adsorption. The adsorption and release of each sucker foot are controlled by the single chip microcomputer, and the movement of the robot is realized at the same time. When the cleaning robot moves to the position to be cleaned, turn on the drum motor switch through the console, the drum motor runs, and the drum starts cleaning. At the same time, the water storage box starts to spray mist droplets onto the glass wall through the nozzle, and the sliding table motor works, driving the whole clean structure part to complete the up and down reciprocating movement. After cleaning, the sewage is collected by the wiper board and guided to the ground by a small pipe, so as to clean the wall.

In the process of cleaning, the whole cleaning robot also moves forward slowly at a certain speed. When the face can not be directly cleaned, through the console, open the hinge motor. Turn the hinge at an Angle so that one side of the cleaning robot is attached to the wall and the other side is released. The robot then repeats until it crosses over.

![General Assembly Drawing](image)

**Figure 1.** General Assembly Drawing
1- Hinge flip mechanism; 2-Walking mechanism; 3-Cleaning device

3. Mechanical Structure Design of the Curtain Wall Cleaning Robot

3.1. Design of Cleaning Device

Cleaning part of the movement is to allow the roller brush to clean at the same time up and down the movement. The same position for repeated cleaning, simulation of manual cleaning of the glass action, to ensure the thorough cleaning. The cleaning speed of this part is fixed. Here, the transmission speed is 0.3m/s. The total mass of the whole curtain wall cleaning robot does not exceed 10kg, requiring smooth movement, simple structure and continuous movement. Combined with the movement speed and characteristics of the cleaning part of the curtain wall cleaning robot, the sliding table screw mechanism is proposed. The screw rod is connected to the motor through the coupling, and the screw rod rotates to drive the sliding table to complete up and down sliding. When the slider reaches the end buffer, the motor reverses immediately. The screw rod rotates in the opposite direction and the sliding table moves in the opposite direction to realize the reciprocating movement of the clean structure.

Sliding table screw structure transmission smooth structure is simple, very consistent with the movement of clean structure[5].

The working parts cleaned by the curtain wall cleaning robot are roller brushes as shown in figure 3-1. Rolling brush through the motor to achieve continuous rotation, cleaning the glass parts. The roller
brush is installed on the drum box. A water tank is attached to the drum box to store the water needed for cleaning. Before work, fill the tank with water through the water inlet on the drum box. When working, the water in the water tank is sprayed to the roller working part through the nozzle, so as to complete the cleaning work.

![Figure 2. The transmission system of the cleaning device](image)

3.2. Design of Walking Mechanism
A sucker foot consists of three suckers. In the process of movement, one of the three suckers of the sucker foot is fixed. The other two suckers take the fixed sucker as the center of the circle and rotate at a certain Angle to fix the next sucker. Follow the steps above to move. The robot moves forward, backward or left and right by controlling the Angle at which the sucker turns.

![Figure 3. The Sucker Foot](image)

The walking of curtain wall cleaning robot is mainly controlled by several suckers, and the suckers are controlled by the pneumatic system, as shown in figure 3 below[6].

![Figure 4. The pneumatic control system](image)

Air source; 2- Gate valve; 3- Air filter; 4- Pressure reducing valve; 5- Separator; 6- Muffler; 7- Two five-way solenoid valve; 8- One-way throttle valve; 9- Cylinder
The air source provides power, which passes through gate valve, air filter, pressure reducing valve and separator successively. Through two five-way solenoid valve to control the pneumatic cylinder process and return. Finally, it leaves through the muffler. Process: two five-way solenoid valve is placed in the left position, and the cylinder moves to the right to complete the adsorption action. Return journey: two five-way solenoid valve is placed in the right position, the cylinder moves to the left, and the sucker is released. Air filters are used to filter air to ensure that no debris enters the cylinder and blocks the pipe. Pressure relief valve is used to control the pressure, when the pressure is too high, it will automatically disconnect the channel, protect the pressure device. One-way throttle valves are used to control the flow rate.

3.3 Design of Flip Mechanism
The material of hinge joint shaft is 45 steel. Hinge shaft is mainly used to connect cleaning devices on both sides together, two hinge shaft control half of the mechanism, through the gear drive. It comes into play when it encounters a different surface. The turnover mechanism needs to realize the turnover of the curtain wall cleaning robot and control the Angle of rotation of the shaft. So the motor choice stepper motor, control with a single chip microcomputer. If the pulse equivalent is 0.001, then 10,000 pulses are equal to one cycle, and 27.7 pulses are equal to one degree. By controlling the number of pulses to ensure the rotation Angle of the turnover mechanism, the purpose of climbing the special-shaped wall can be achieved.

4. Design of Curtain Wall Cleaning Robot Control System

4.1 Selection of Curtain Wall Cleaning Robot Controller
The curtain wall cleaning robot has simple structure, fixed action and simple operation. Therefore, the controller also requires simple operation, good reliability and easy maintenance. According to these characteristics, FX2N PLC controller is selected. The specific I/O distribution table is shown in table 2.

| Input point | Code name | Function       | Output point | Code name | Function       |
|-------------|-----------|----------------|--------------|-----------|----------------|
| X0          | SA1       | manual         | Y0           | YV1       | Motor start    |
| X1          | SA2       | automatic      | Y1           | YV2       | Roller rotation|
| X2          | SB1       | Start button   | Y2           | KM1       | The pump work  |
| X3          | SB2       | Drum motor     | Y3           | KM2       | The slide table moves upward |
| X4          | SB3       | The water valve switch | Y4 | KM3 | Pneumatic pump operation |
| X5          | SB4       | Slide table motor switch | Y5 | KM4 | The slide table moves downward |
| X6          | SB5       | Valve switch   | Y6           | HL1       | Power indicator light |
| X7          | SB6       | Light switch   | Y7           | HL2       | Water pump indicator light |
| X8          | XB7       | Stop           | Y8           | HL3       | Pneumatic pump indicator light |
|             |           |                | Y9           | HL4       | floodlight     |

4.2 Function Design of Curtain Wall Cleaning Robot Control System
This paper mainly designs the cleaning part control system of curtain wall cleaning robot. Now analyze the cleaning steps in a single cycle. When the curtain wall cleaning robot is at the origin, the water valve opens and begins to discharge water. Then the drum motor opens and the drum starts to turn. The sliding table motor starts to turn forward and the sliding table moves towards the end point. When the end point is reached, the motor reverses and the sliding table moves downward until it
returns to the origin. Then the sliding table motor is closed, the drum motor and the water valve are closed in turn to complete a cycle.

5. Conclusion
This paper designs the overall scheme of curtain wall cleaning robot and completes the mechanical structure design, including cleaning structure, moving mechanism and turnover structure. Solidworks is used for 3d modeling of curtain wall cleaning robot. Based on PLC, the control system of curtain wall cleaning robot is designed. The innovation of this paper lies in the design of a hinge flip mechanism to achieve the purpose of climbing different surfaces.

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