Obstacle-surpassing Mechanism of Autonomous Obstacle-surpassing Glass-cleaning Robot and Robot Thereof

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Abstract: With the advancement of technology, intelligent glass-wiping robots have entered people's lives. In order to solve the problem that the current glass-wiping robot cannot cross the window frame autonomously, a glass-wiping robot capable of autonomous obstacle-crossing is designed. It uses the advantages of the glass-wiping robot that has been put on the market to plan paths and detect window frames. An autonomous obstacle-crossing system, which includes a host, a main suction cup, a lifting mechanism, two obstacle-crossing mechanisms, and two support mechanisms. This article will elaborate on the mechanical structure, cross-obstacle function and principle of the obstacle-crossing system, and analyze the feasibility of the design scheme. The autonomous obstacle-clearing glass-cleaning robot proposed in this paper can complete the wiping of multiple pieces of glass alone without the presence of the user, which improves the robot's autonomy and work efficiency, can ensure the safety of the user, and truly liberates Human intelligent glass-wiping robots have certain practical significance.

Keywords: Obstacle-crossing mechanism; Cylinder; Mechanical design

1. Introduction

Aiming at the problem that domestic glass-wiping robots cannot automatically cross the window frame to complete the cleaning work on other glass, this paper proposes a self-obstacle-crossing glass-wiping robot, which is adsorbed on the glass surface by a micro vacuum pump and cooperates with a micro air pump to make the obstacle crossing mechanism flexible The action completes the obstacle-crossing function, the robot does not need manual care during the cleaning process, and can automatically clean multiple glass surfaces, which is more intelligent and flexible.

2. Mechanical Design

This paper proposes an autonomous obstacle-crossing glass-wiping robot, as shown in Figure 1 below. The obstacle-crossing system includes a host, a main suction cup, two suction cup groups, a lifting mechanism, two obstacle-crossing mechanisms, and two supporting mechanisms. The lifting mechanism, obstacle crossing structure and supporting mechanism contain cylinders and solenoid valves. The expansion and contraction of the cylinder is controlled by the opening and closing solenoid valves of the control system. The expansion and contraction power of the cylinder is provided by an external miniature air pump. The adsorption force of the main suction cup and the suction cup group is Provided by the miniature vacuum pump in the second body. Multiple distance measuring sensors are installed around the outer wall of the main unit to detect the distance between the main unit and the glass frame. When the distance detected by the distance measuring sensor is less than a preset distance and meets the obstacle crossing conditions specified by the control system, the main unit will autonomously cross over The obstacle between the glass drives the robot to cross from the glass surface that has been cleaned to the glass surface to be cleaned. In addition, the robot relies on the bottom motor to drive the crawler to achieve the movement function. The bottom of the robot is surrounded by a cleaning cloth, and only a certain amount of water is sprayed in the cleaning cloth when in use. See the appendix for specific graphic information.

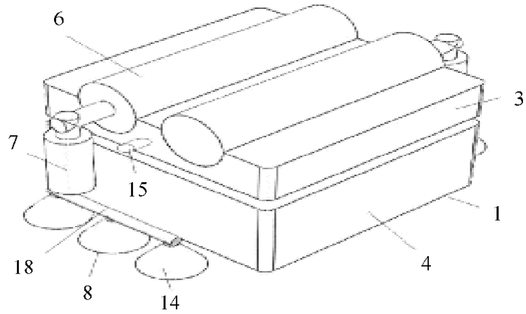

Figure 1. Autonomous obstacle-crossing glass cleaning robot

The cylinders mentioned above are all single-acting telescopic sleeve cylinders, which are assembled from two-stage piston cylinders, as shown in Figure 2, and are mainly composed of cylinder head, cylinder tube, sleeve, piston and other parts. The extension sequence of the telescopic cylinder piston is based on the effective working area of the piston. The larger effective area moves first and the smaller one moves later; while the no-load retracting sequence is reversed. The thrust and speed during extension change in stages, the effective area of the large piston is large, the thrust during extension is large, the speed is low, and the thrust during extension of the secondary piston is small and the speed is high, and it is reset by the return spring.

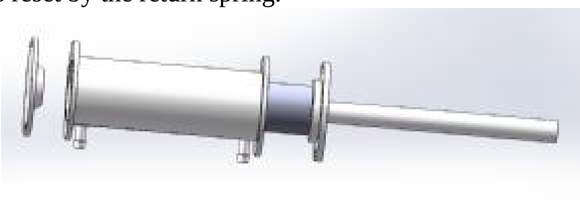

Figure 2. Schematic diagram of single-acting telescopic sleeve cylinder

3. Cross-obstacle Analysis

The vacuum source is used to provide vacuum air pressure to each cylinder, main suction cup and vacuum suction cup group; the filter is used to filter out particulate matter in the air sucked from each cylinder, main suction cup and vacuum suction cup group. The main suction cup and the vacuum suction cup group provide adsorption force by drawing the vacuum source in the suction cup by a vacuum pump; the compressed air in the cylinder is provided by an external miniature air pump. One cavity of the cylinder is connected to the atmosphere, and the other cavity is the air inlet cavity. When the air cavity enters the compressed air, the two sides of the piston move due to the pressure difference, that is, the piston rod extends and retracts. Cooperate with multiple solenoid valves to achieve the target action by connecting different positions to form different paths.

The solenoid valves used are all two-position three-way solenoid valves, used to open and close the cylinder, and adjust the telescopic length by controlling the gas flow in the cylinder. When crossing obstacles, take the action of the lifting mechanism as an example: the solenoid valve 3 is connected to the right position, the compressed gas enters the lifting cylinder 5, the piston rod extends upward, and the body is lifted. When not crossing obstacles, the solenoid valves of the two obstacle crossing mechanisms and the two supporting mechanisms are all connected to the left position, and the solenoid valve 2'of the lifting mechanism is connected to the right position. A negative pressure is generated in the main suction cup 2, which absorbs on the glass surface, the driving motor drives the robot to move.

4. Design Process

4.1. Selection of miniature air pump model

Since the robot is working on the wall, considering its safety and reducing the weight of the robot, ABS engineering plastic is selected as the material of the cylinder. The output force of a single-acting telescopic sleeve cylinder depends on the effective area of the negative pressure acting on the secondary piston of the cylinder. The friction between the piston and the cylinder and the elastic force of the return spring are expressed in the form of load rate.

The effective area of the negative pressure acting on the cylinder piston:

$$A=\frac{p}{4}\cdot\left(D_1^2\text{-}D_2^2\right) \tag{1}$$

Suppose the total mass of the robot is $m=5\text{kg}$, so $P=34.35\text{Kpa}$.

Considering the influence of actual factors such as leakage, gas compressibility, friction force, inertia force, etc., the air pump model FAT401.2 is selected, and its parameter characteristics are shown in Table 1. In addition, auxiliary components such as filters, silicone tubes, and silencers are also required.

Table 1. FAT401.2 parameter characteristics

Model	Voltage (V DC)	Load current (mA)	Flow rate (L/Mmin)		Relative vacuum degree (Kpa)	Maximum output pressure (Kpa)	Continuous load operating life (Hours)
			Peak flow rate	Average flow rate			
FAT401.2	12	〈380	1.2	1	-28	40	⩾1200
	24	〈190		0.9			⩾2400

4.2. Design and verification of single-acting telescopic sleeve cylinder

Take the design and verification of the obstacle-crossing cylinder as an example.

4.2.1. Primary cylinder and large cylinder

The inner diameter of the first stage cylinder:

$$D=\sqrt{\frac{4F}{ph\,p}} \tag{2}$$

The wall thickness of the primary cylinder:

$$d=\frac{p_1 D}{2[s]}+C \tag{3}$$

$$[s]=\frac{S_b}{n} \qquad (4)$$

Considering the influence of actual factors such as leakage, gas compressibility, friction force, inertial force, etc., given a certain margin, $D=39.89\text{mm}$, so the inner diameter of the first-stage cylinder is set to 40mm,and the inner diameter of the first-stage cylinder is determined to be $D_3=64\text{mm}$.It is calculated that the wall thickness of the primary cylinder is 2mm, and the wall thickness of the large cylinder is 0.20mm.

4.2.2. Secondary piston and piston rod

The secondary piston and piston rod are made into one piece.

Size of secondary piston and piston rod

It can be seen from the above that the diameter of the secondary piston is $D_1=D=40\text{mm}$. According to the "Common Cylinder Theoretical Output Force Table", the diameter of the piston rod is $D_2=14\text{mm}$.

Check the strength of the piston rod

Because of $L\le 10D_2$. At this time, the failure mode of the piston rod is mainly strength failure. Check the diameter of the piston according to the strength conditions, namely.

$$d\ge\sqrt{\frac{4F}{p[s]}} \qquad (5)$$

Available, $D_2=14\text{mm}\ge 2.27\text{mm}$, Therefore, the stability and strength of the piston rod meet the requirements.

Check the cylinder head fixing bolt:

$$d_s\ge\sqrt{\frac{5.2kF}{pz[s]}} \qquad (6)$$

$$F=\frac{pD^2}{4}\cdot p \qquad (7)$$

Substitute the above formula, $d_s\ge 0.622517\text{mm}$, so $d_s=5\text{mm}$, Can meet the requirements of cylinder head sealing.

4.2.3. Cylinder movement speed

The movement speed of the cylinder depends on the flow rate of the air pump, namely:

$$v=\frac{Q}{A}=\frac{Q}{\frac{p}{4}d^2} \qquad (8)$$

Substitute $D_3=64\text{mm}=6.4\text{cm}$ into the above formula to get the output speed of the first stage piston sleeve: $v_1=0.518\text{cm/s}=5.18\text{mm/s}$

Substitute $D=40\text{mm}=4\text{cm}$ into the above formula to get the output speed of the first stage piston sleeve: $v_2=1.327\text{cm}/s=13.27\text{mm}/s$

5. Two-stage Piston Stroke

According to the comprehensive consideration of the size of the moving component and the distance across the obstacle, the stroke of the secondary piston is taken as $S=600\text{mm}$.

The relevant parameters of the first-stage cylinder, the second-stage piston, the second-stage piston rod, and the large cylinder are calculated above, and they are checked in consideration of environmental factors to ensure that the cylinder design has sufficient margin in practical applications. It further proves the feasibility of the design scheme.

6. Selection and Verification of Suction Cups

6.1. Selection of miniature vacuum pump model

Choose VKY5008 miniature vacuum pump to provide the negative pressure of the robot vacuum sucker, and its parameter characteristics are shown in Table 2.

Table 2. Parameter characteristics of VKY5008 mini vacuum pump

Model	Voltage(VDC)	Current(mA)	Power(W)	Flow(L/min)		Relative vacuum (negative pressure) (KPa)
				Peak flow	Average flow	
VKY5008	12	〈500	〈6.0	8	4.5	≈-50
	24	〈240	〈5.76			

Choose two sets of vacuum suction cups, each group has 3 vacuum suction cups, the diameter of the suction cups:

$$D\ge\sqrt{\frac{4Wn}{pNp_2}} \qquad (9)$$

It can be seen from Table 3 above that the micro vacuum pump can provide a relative vacuum of 50Kpa, So $p_2=50\text{Kpa}=0.05\text{Mpa}$; Substitute the above formula to get $D\ge 45.13\text{mm}$.

Because the vacuum pressure deforms the suction cup, the suction area is smaller than the diameter of the suction cup. Therefore, a margin should be left when calculating the diameter of the suction cup.

The known adsorption area is:

$$S=\frac{pD^2}{4} \qquad (10)$$

Substitute $D_{min}=45.13\text{mm}$ into the formula to get $S_{min}=1598.82\text{mm}^2$.

Substitute $D=60\text{mm}$, $S=\frac{pD^2}{4}\times 90\%=2543.4\text{mm}^2>S_{min}$

So the suction cup of $D = 60mm$ is feasible, and its effective diameter is $54mm$.

6.2. Check of vacuum suction cup

When the robot is working, there are two dangerous situations when it crosses obstacles on the glass wall: one situation is that the robot slips off the wall; the other situation is that the suction cup that is in contact at the top is detached due to the overturning moment. The wall causes the robot to tip over. In the design, the adsorption mechanism of the robot should avoid two situations of sliding and tipping. In order to simplify the analysis and calculation, only the static adsorption situation is considered here.

6.2.1. Slipping situation

A. Suction cup load
According to the design requirements, the suction cup is installed vertically, and the holding force of the suction cup moving in the vertical direction is:

$$F_H = m \cdot (\frac{g+a}{m}) \cdot s \quad (11)$$

Substitute into the above formula, get $F_H = 196.2N$.
B. Theoretical retention
In order for the suction cup to be adsorbed on the surface of the workpiece, the theoretical holding force should be greater than the suction cup holding force FH, that is:

$$\frac{p}{4} \cdot D_e^2 \cdot p_u \cdot n \geq 196.2N \quad (12)$$

6.2.2. Overturning situation

Take the entire robot as the research object and conduct force analysis. In order to keep the robot in equilibrium without tipping over, the main force is the gravity of the entire robot, and the restraining force is the suction force of the suction cup. These two forces must satisfy the balance condition, that is, the balance equation of the plane parallel force system. When the suction cup is adsorbed vertically, the robot is in a balanced state where it may turn around the edge A of the lowermost suction cup and tip over. At this time, the restraining reaction force of the uppermost suction cup F=0, that is, the suction cup and the wall will be separated from the suction. At this time, the balance equation can be used to find the minimum adsorption force F_{min} between a single suction cup and the wall, so as to find the minimum air pressure P_{min} that maintains the suction between the suction cup and the wall, so only the equation $\sum M_A = 0$ can be used to obtain F_{min}, thereby obtaining P_{min}.
So

$$G \cdot h + 2 \cdot F_{min}(L + L_1) = 0 \quad (13)$$

Solutions have to $F_{min} = 7.14N$.

Then you can find the minimum air pressure to maintain the suction cup and the wall P_{min} :, Substitute in the solution $P_{min} = 2.8Kpa$,There are a total of 6 vacuum suction cups. Then $P_{sum} = 16.8Kpa$, because the vacuum degree provided by the VKY5008 miniature vacuum pump is -50KPa, $50Kpa > 16.8Kpa$, it meets the vacuum pump selection and the suction cup design plan to meet the strength requirements.

7. Conclusion

This article proposes an autonomous obstacle-crossing glass-wiping robot, and mainly introduces the mechanical structure of the autonomous obstacle-crossing glass-wiping robot. Analyzed the obstacle-crossing method of the glass-wiping robot from the physical actions of the robot; analyzed the obstacle-crossing principle of the glass-wiping robot from the air movement of the robot. The design structure of the glass cleaner obstacle crossing system is introduced in detail and its feasibility is verified. It can be seen that the design of this article takes into account multiple factors such as the environment, and reserves enough for the implementation plan in the selection and cylinder design. The margin ensures the reliability and feasibility of the obstacle-crossing system design proposed in this paper, and makes the obstacle-crossing mechanism of the glass-cleaning robot proposed in this paper flexible, lightweight and highly practical. In order to realize an autonomous obstacle-crossing glass cleaner the robot laid a solid foundation.

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References

[1] Guo D., Su Z., Sun S., et al. A new feedback-added obstacle avoidance scheme for motion planning of redundant robot manipulators. 2017 29th Chinese Control and Decision Conference (CCDC). 2017, 441-446.

[2] Anonymous. No need for water cooling of valve-gate actuators. Plastics Technology. 2019, 65(6).

[3] Mohamed G. Alkalla, Mohamed A. Fanni, Abdel-Fattah Mohamed, Shuji Hashimoto, Hideyuki Sawada, Takanobu Miwa, Amr Hamed. EJBot-II: An optimized skid-steering propeller-type climbing robot with transition mechanism. Advanced Robotics. 2019, 33(20).

[4] Xu Fengyu, Meng Fanchang, Jiang Quansheng, Peng Gaoliang. Grappling claws for a robot to climb rough wall surfaces: Mechanical design, grasping algorithm, and experiments. Robotics and Autonomous Systems. 2020, 128.

[5] Mukherjee R., Minor M.A., Pukrushpan J.T. Motion planning for a spherical mobile robot: revisiting the classical ball-plate problem. Journal of Dynamic Systems Measurement and Control. 2002, 124(4), 502-511.