Autonomous Air Duct Cleaning Robot System

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Abstract **This paper presents a new type of autonomous air duct cleaning robot system, which consists of three devices: the monitor and control device, the remote robot and the dust collection device. The control principle and structure design of the proposed robot system are introduced. The guiding device is proposed and designed to ensure the remote robot to move in straight route and turn automatically at corner. The control mechanisms of the remote robot and the rotating brush device are described in detail. In this paper, the 3D model of the remote robot is created and the assembly analysis is accomplished using Pro/E. Finally, a prototype of the rotating brush device is made manually to test the cleaning effect of the proposed robot system.**

I. Introduction

Numerous studies by government and environment health specialists have shown indoor air to be a significant environmental threat to human health [1]. Exposure to these contaminants has led to a health concern known as "sick building syndrome" or "SBS". Statistics show that 1 out of 5 (50 million) Americans suffer from allergies caused by substances found in the home and office. Deaths related to asthma have risen 40% in the past two decades [2]. Studies in China also show that 40% — 53% indoor air pollution sources are caused by contaminated ducts of central air-conditioning [3]. More than 75% of the air ducts are highly contaminated [4]. However, research shows that mildew and bacteria in air will not be diffused if they did not attach the dust. So dust — the spreading medium must be cleared in order to cut down the source of contamination. Therefore, the air duct of central air-conditioning is supposed to be cleaned regularly.

People realized this problem around the mid 1980s and began employing robotic tools to clean ductwork [5, 6]. In recent years the air duct cleaning industry has discovered another use for robotic equipments [7, 8]. The use of robotics helps to reduce the labor involved in the cleaning of air ducts. But these robotic equipments still can not realize auto control and need operators trained well. To reduce the task of the operators, in this paper, a new type of autonomous cleaning robot system is proposed to clear the rectangular air ducts. This proposed system is composed of monitor and control device, remote robot and dust collection device. The control principle and structure design of the remote robot are introduced in the following section. The guiding device is proposed and designed to ensure the remote robot to move in straight route and turn automatically at corner. The control mechanisms of the remote robot and the rotating brush device are introduced in detail. The 3D model of the remote robot was created and the assembly analysis is accomplished using Pro/E. Finally, a prototype of the rotating brush device is made manually to test the cleaning effect of the robot system.

II. Duct Cleaning Robot System

The proposed robot system is designed to clean the rectangle air ducts:

Width: ranging from 400mm to 1000mm;

Height ranging from 120mm to 1000mm;

During this range, the remote robot can travel fluently in the elbow of the air ducts, which can be test using the model introduced in [9]. The working process of our proposed robot system is summarized as follows (Fig.1):

① Inspect the inner of air duct and record the "before" cleaning condition of the duct;

② Airproof the air duct using air cells;

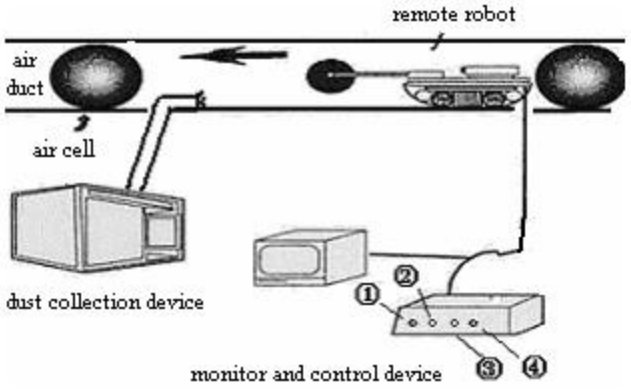

Figure1. Scheme of working process of the robot system

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③ Clear the wall of air ducts and blow dust forward;
④ Collect the dust and other contaminants;
⑤ Record the "after" cleaning condition of the duct;
⑥ Remove the air cell.

The autonomous air duct cleaning robot system is composed of three parts: ①monitor and control device; ② remote robot; ③ dust collection device. The control principle and the structure design of each part will be introduced below:

A. Monitor and Control Device

Monitor and control device consists of monitor unit and control unit. Operators can inspect the working conditions of the remote robot on monitor. The "before" and "after" cleaning condition of air ducts can also be recorded to be reviewed by the customer in future. The control unit has four buttons as shown in Fig.1: ① and ② are used to drive the robot to move forward or backward by controlling the turning of the electromotor; ③ is used to drive the guiding wheels to rotate synchronously in the same speed but different direction; ④ is used to actuate the pneumatic rotating brush and the dust collection device.

B. Remote Robot

Remote robot is the main part of the whole system. It is composed of video device, driving and guiding device and rotating brush device (Fig.2). The dimension of the remote robot is 280mm (length) * 240mm (width)* 120mm (height). The guiding device is proposed to ensure the robot to move in straight route and turn automatically at corner. The control mechanisms and the function of each device are shown below:

1) Video device

The video device is composed of one video camera (CMOS) and two halogen lamps. The camera is connected with the monitor using parrelle intefaces. All the clearing process can be inspected and be recorded to keep in the archives.

The height, the pivoting and rotating angle of the device can be adjusted in order to provide maximum all round

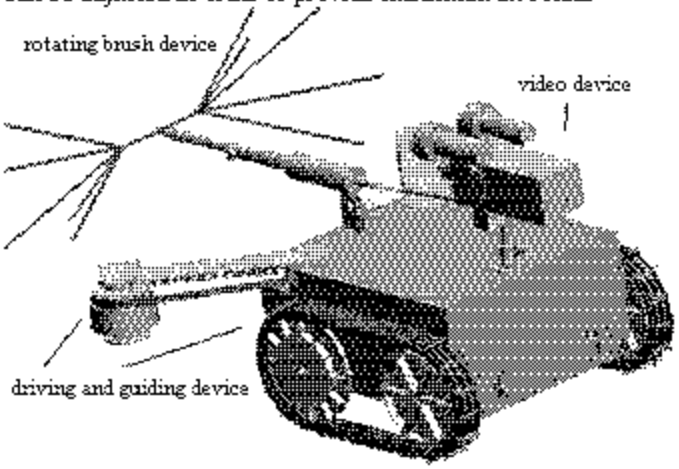

Figure2. 3D model of remote robot

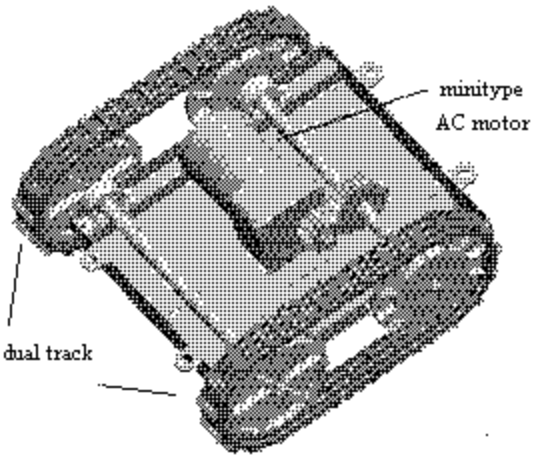

Figure3. Driving device

scanning in different types of air ducts. The principle of adjustment is similar to the height adjustment of the tripod.

2) Driving and guiding device

Fig.3 shows the driving device. In order to increase the friction when the robot is moving, dual rubber track drive is employed. Because the friction coefficient between the rubber and steel is 0.8, which is 5.8 times of plastic and steel and is 4.7 times of Aluminum alloy and steel; and the contact area between the track and the duct is much bigger than the wheel without track.

Two guiding wheels (Fig.2) are mounted in the front of the remote robot acted as its left and right arms, which is actuated respectively by two minitype AC electro motors. The transverse distance between these two guiding wheels is designed to be adjustable so that before cleaning, each guiding wheel is adjusted to be 20mm away from the relevant side of the air duct when the robot stands in the central axis of the duct. Once the robot starts, these two guiding wheels will rotate synchronously in the same speed but in reverse direction (left wheel rotates anticlockwise; while, right wheel rotates clockwise). And their tangential speed is a little bigger than the robot's moving speed. So once the left arm contacts the left side of the duct, the Torque M (the Tangential Friction Φ can be converted into the Pulling Force Φ' and the Torque M, as shown in Fig.4) will force the robot to turn right. The principle of turning left is the same.

In this guiding device, ring gear HTD timing belt is employed since it can transfer high-power in low speed, work well in harsh environment and have good wearability and few noises.

3) Pneumatic rotating brush device

Pneumatic rotating brush device is the hard core part in sweeping process. Its 3D solid model and its experimental model are shown respectively in Fig.2 and Fig.5. The mechanism connecting the brush and the pneumatic motor consists of a solenoid and a screw. The screw can be drawn out and drawn in to adjust the length of this mechanism and then use a bolt to rivet it. The principle is something like

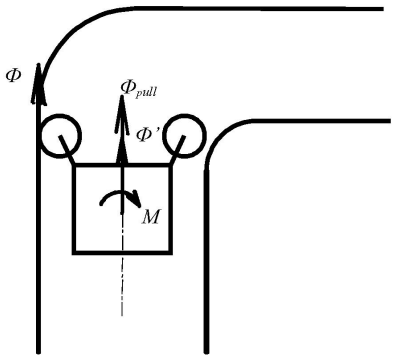

Figure4. Schematic map when robot turning left

adjusting the height of the tripod. The pivoting angle of this device can also be adjusted like this so that all of the walls and corners in different dimension types of air ducts can be reached. Once the brush begins sweeping, the compressed air coming from the hole of the connecting mechanism will blow the dust forward. In the other end, the high-power dust collecting device will inhale all the dust.

The brush head is removable, and has six sets of different dimension types and four kinds of different material type including nylon, steel, stainless steel and copper. Nylon brush head suits air ducts of various materials, and it will not scrape the wall; Steel brush head suits steel ducts; Stainless steel head suits titanium alloy and albata ducts; While, copper brush head suits nonferrous metal ducts.

The bristle of the rotating brush can also be modeled using large deformation elastic theory and can be presented combined with the MathCAD software.

Air drag may affect considerably the deflection of a bristle since air drag increases the torque needed and reduces somewhat the contact force between a bristle tip and the duct surface [9-10]. But at high rotation speeds, air drag only has slight effect on the deflection of the bristles. That can be testified by experiment. The experimental model of the rotating brush device is made manually (Fig.5). The cleaning experiments were done in steel air ducts using four different sets of brush heads (rotating speed n = 8000 r/min). The cleaning effect is good and the deflection of the rotating bristle can be ignored.

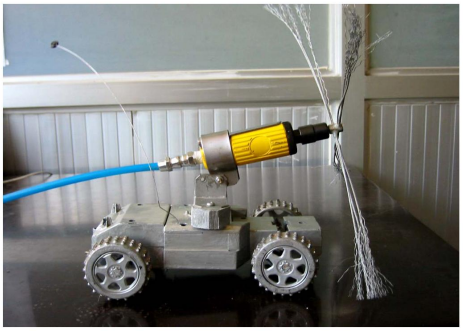

Figure5. Experimental model of rotating brush device

C. *Dust collection device*

Dust collection device is actuated by high power electromotor. It is composed of collection unit and depurating unit (Fig.1). The collection unit inhales air with dust, debris and other contaminants and collects the contaminants in bag. While, the depurating unit filtrates the dirty air and lets out pure air.

In conclusion, the proposed autonomous air duct cleaning robot system has the following merits:

① Clear automatically: the remote robot can clear the duct forward and backward and turn at corner automatically;

② Control visually: Operators can follow the monitor while operating, and all the cleaning process can be recorded on the built-in video recorder.

③ Clean completely: a set of pneumatic rotating brushes with different materials and dimensions are operated within your ductwork's dimension according to National Air Duct Cleaners Association (NADCA) standard;

④ Manufacture easily: The remote robot is designed with modular structure to save the manufacturing cost and time.

III. CONCLUSIONS

In this paper, the new type of autonomous air duct cleaning robot system is proposed, which consists of three devices: the monitor and control device, the remote robot and the dust collection device. The control principle and structure design of each device of the proposed robot system are introduced. The guiding device is developed to ensure the remote robot to move in straight route and turn automatically at corner. The control mechanisms of the remote robot and the rotating brush device are introduced in detail. Also the 3D model of the remote robot is created and the assembly analysis is accomplished using Pro/E. Finally, a prototype of the rotating brush device is made manually to test the cleaning effect of the proposed robot system.

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