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Researches on a wall-climbing robot based on electromagnetic adsorption

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Abstract—**Wall-climbing robots have wide application in industry and other fields. At present, the technical bottleneck of the wall-climbing robots based on magnetic adsorption is that the magnetic force is not only the adsorption force but also the moving resistance force. The bigger the adsorption force is, the bigger the moving resistance force is. In order to solve this problem, a unique wall-climbing robot based on electromagnetic adsorption is proposed in this paper. Electromagnets fixed in the synchronous belts get into or out of work in turn to realize the unity of adsorption and mobility. An embedded Linux system is constructed to transport videos from the robot to the handheld terminal in real time. A MCS-51 based controller is designed to perform robot control. A prototype robot is manufactured and tested. Experiments show the video delay is less 0.45s and the remote-control distance is beyond 80m.**

Keywords—wall-climbing robot, electromagnetic absorption, embedded control

I. INTRODUCTION

Wall-climbing robot, taking the place of human beings in dangerous, boring and heavy work, can be widely used in high-altitude working environments such as de-rusting and flaw detection in the shipping industry, cleaning of the outer surface of large buildings, anti-terrorism reconnaissance, painting and flaw detection of large oil tanks in petrochemical industry, capacity measurement of metal tanks, fan leaves of large-scale wind power generation maintenance and other fields. According to serving environment and working media, the adsorption modes for wall-climbing robots are classified into negative pressure adsorption[1-2], bionic dry adhesive adsorption[3-4], magnetic adsorption and etc. Negative pressure adsorption is not limited by working media, but it will suffer from air leakage if the surface is very rough. Bionic dry adhesive adsorption is suitable for all kind of surfaces, and magnetic adsorption only works for magnetic-conductor. Magnetic adsorption includes electromagnetic adsorption, permanent magnetic adsorption and their combination. As to magnetic adsorption, many researches are focused on permanent magnetic adsorption[5-8]. A few of researches are based on electromagnetic adsorption[9]. Extensive researches have been carried on wall-climbing robots for many years, but there is few prototype wall-climbing robot which is suitable for actual uses until now. One of the technical bottlenecks is the unity of adsorption and mobility.

II. OVERALL DESIGN

In this paper, a unique structure is proposed to solve the above problems. As shown in Figure 1, the wall-climbing robot is composed of a main frame, two synchronous belts with embedded electromagnets, two conductive troughs, four synchronous belt wheels, two step motors and its controllers, and etc. The conductive plate provides electric power for the electromagnet. 16 electromagnets are fixed in a synchronous belt equidistantly. The U-shaped conductive trough is arranged inside the synchronous belt. When the synchronous belt wheels are driven to rotate, the electromagnets will be brought into and out of contact with the conductive trough one by one. That is, only these electromagnets which contact with the conductive trough can generate magnetic force. In this way, when the wall-climbing robot moves forward, the electromagnets will get into or out of work in turn. As to our prototype, six electromagnets always stick to the wall surface at the same time to support the whole robot. According to this scheme, the magnetic force is only the adsorption force instead of the resistance force. The problem of unity of adsorption and mobility has been effectively solved.

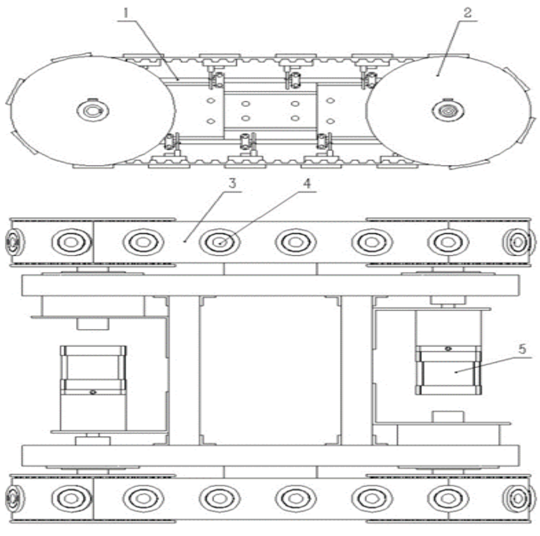

Fig. 1. The plane assembly drawing of wall-climbing robot

1-Conductive plate, 2-Timing belt pulley,3-Timing belt, 4-Electromagnet, 5-Stepper motor

In addition, the main frame is made of aluminum alloy in order to reduce the weight. The robot outline is 335mm*295 mm, and the wheel is 106mm in diameter. A camera on the robot is employed to capture videos and the operator can watch the pictures displayed on the screen of a handheld terminal.

In this paper, comprehensive consideration of different forms of controls, the control system of the wall-climbing robot uses two distributed control systems which are hand-hold terminal control and vehicle on-board controller. The overall block diagram of the control part of the wall climbing robot is shown in Figure 2. The main function of the wall-climbing robot's hand-held terminal is to send the control signal to the vehicle-mounted controller by wireless transmission so as to realize the remote-controlled movement of the wall-climbing robot. The on-board controller, the execution layer of the wall-climbing robot control system, has two main functions: one is to control the climbing robot's forward, backward and steering on the wall, and the other is to communicate with the hand-held terminal by wireless communication. The microcontroller of on-board controller will immediately execute the appropriate procedures to control the stepper motors after receiving the command signals, and then it can control the motions of the wall-climbing robot.

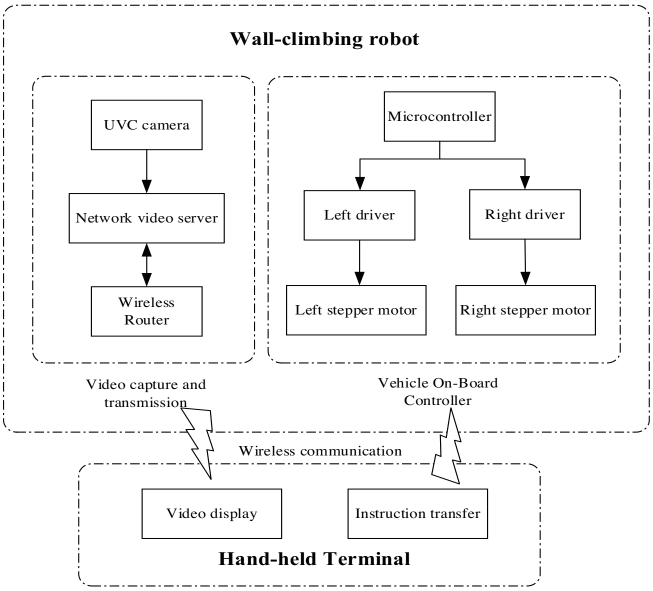

Fig. 2. Block diagram of control system of derusting wall-climbing robot

III. DESIGN OF THE CONTROL SYSTEM

A. Hardware Design

Based on a MCS-51controller, remote-controlled and image wireless transmission are realized. Due to the long distance control and light load requirements, the way of no cable mode is chosen. In this paper, we select 7.4V 1500mA lithium battery as the control system power supply, and obtain the 5V power supply circuit and 3.3V power supply circuit through the AMS1117 series of positive low-voltage step-down regulator chip. In addition, the above two power conversion circuits add 10μF and 0.1μF capacitors to the input and output terminals , which can effectively filter and stabilize the voltage, thereby increasing the reliability of the control system.

The hardware circuit of the entire on-board control system is composed of STC12C5A60S2 microcontroller, stepper motor drive circuit, wireless receiving circuit, power conversion circuit and serial port download circuit. The wireless receiving circuit is responsible for constantly receiving the control instructions issued by the hand-held terminal. The control signals are resolved by the microcontroller as the output of the pulse command to the stepper motor driver. Because the stepper motor and electromagnet selected by this paper needs 24V DC power supply, which is connected by two 12V batteries in series. The 5V voltage of the on-board controller is obtained by step-down using the 24V to 5V power isolation module B2405LS-1W.

B. Software design

The software design of the control system is mainly divided into that of the handheld terminal and the vehicle controller. The program of the handheld terminal is used to control the whole motion of the wall-climbing robot; the program of the vehicle on-board controller controls the motion of the wall-climbing robot according to the instructions of the hand-held terminal received from the wireless transmission module.

Using the interrupt mode, the main function of hand-held terminal is to send command data to vehicle on-board controller through the wireless transmission module according to external keyboard input. The software of the vehicle controller includes wireless transmission and stepper motor driving. The wireless reception subroutine is for receiving control instructions issued by hand-held terminal.

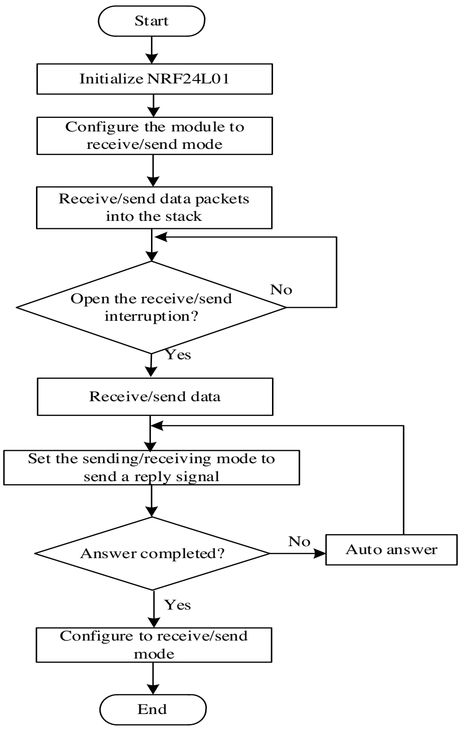

Fig. 3. Subroutine for Wireless receiver/ transmission

The instruction transmission of hand-held terminal and vehicle controller use wireless radio frequency technology and wireless transceiver module NRF24L01 to achieve the instruction transfer. The flow chart of receiving and sending subroutines is shown in Figure 3.

IV. WIRELESS IMAGE TRANSMISSION

In this paper, we use the wireless video image transmission method to observe the surface defects of large steel structures. The operator can observe the video image captured by the video acquisition terminal carried on the remote wall-climbing robot on the ground. The hardware equipment needed for wireless video transmission is embedded development board, router, LCD display and UVC camera. The software development process is divided into the construction of the Linux system software development environment and the construction of the video image acquisition part, as shown in Figure 4 and Figure 5.

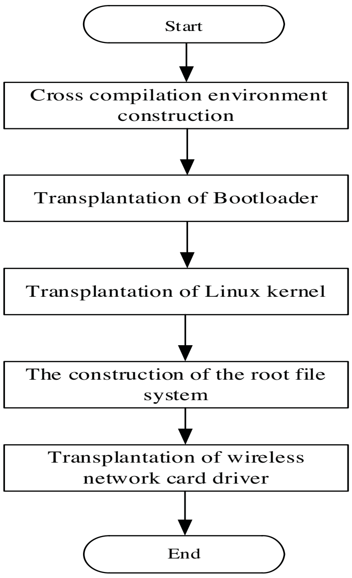

Fig. 4. The steps of building the software development environment of Linux system

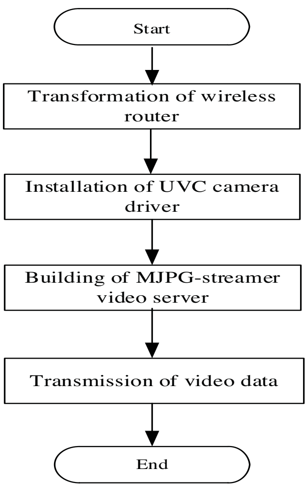

Fig. 5. Building of video image acquisition part

V. RESULTS AND CONCLUSION

The video capture and transmission system, used to collect inspection images and remote control robot, is mounted on the climbing robot to form the experimental system. A prototype robot was designed and manufactured, as shown in Figure 6.

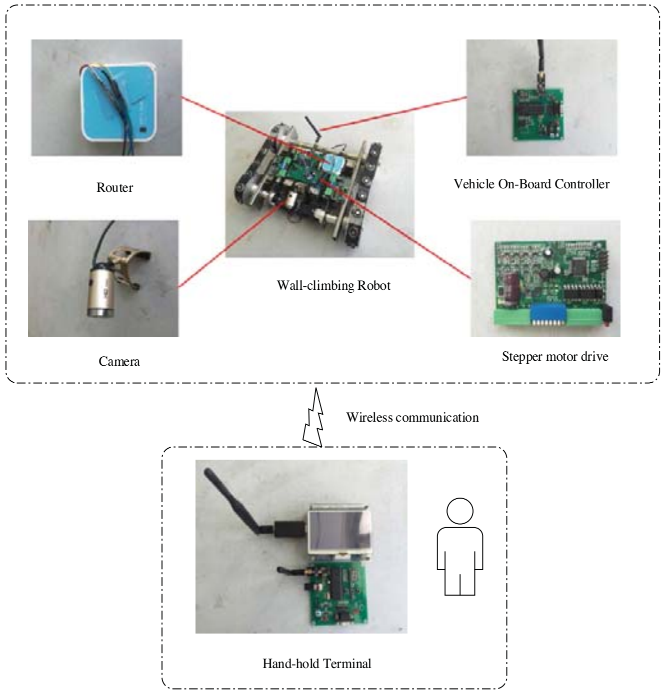

Fig. 6. Composition diagram of experimental system

As shown in Figure 7, the LCD display can be clearly displayed video data. Thus, the successful wireless video transmission experiment, video capture and transmission system basically completed. After many experiments, it is proved that the video image captured by the front camera can be stably transmitted in a distance of about 80m through the LAN which is constructed by the router and connected by the wireless network card.

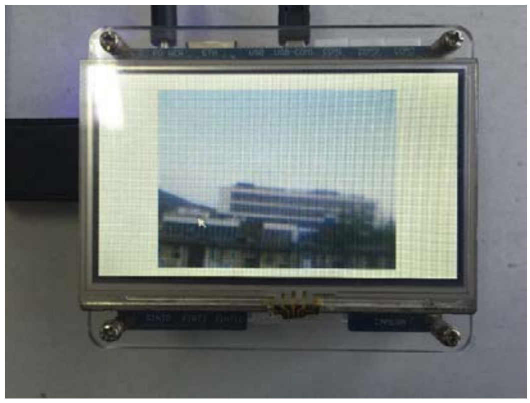

Fig. 7. Video data display

After the success of the video transmission, the screen of the mobile stopwatch captured by the camera is compared with the stopwatch in the LCD display to test the delay of the video image, as shown in Figure 8. The video transmission delay in

0.2s ~ 0.45s shown in Table I. Experiment shows the video delay is less than 0.45 seconds and the remote control distance is over 80m. Since the robot moves slowly in routine inspection, the delay is acceptable in our application.

(a) (b)

Fig. 8. Latency test diagram

TABLE I. MAIN DIRECTORY OF ROOT FILE SYSTEM(UNIT:SECOND)

Actual stopwatch timer	LCD display	Delay
03:29.26	03:29.06	0.20
03:39.37	03:38.93	0.44
03:40.58	03:40.13	0.45
03:42.37	03:41.95	0.42
03:44.04	03:43.75	0.29

When the wall-climbing robot moves forward, the electromagnetic attraction mechanism designed in this paper contacts and disengages the electromagnets one by one from the conductive grooves. This design innovatively solves the problem of unity of adsorption and mobility. We have also designed a remote control system with video transmission function, which can make it more convenient for the staff to carry out daily inspection work on large steel structure machinery.

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