Study of Control System for Climbing Robot based on Multi-sensor

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Abstract: In this paper, the modular design idea and MVC design pattern are used to study a control system of a wall-climbing robot applied to detecting the surface of large-scale tanks. The design mainly has two parts: hardware system and software system. The hardware system consists of power modules, sensor modules, control modules, and communication modules. The software system is composed of the robot control software, the robot remote control App based on Android devices, and the upper computer application program which can run in both Windows system and Linux system. Finally, the feasibility and robustness of the system are verified by experiments.

1. Introduction
Currently, the robot is a wide range of manifestations of sorts [1]. Among them, wall-climbing robots have gradually begun to serve in different aspects of life. In China, the Robot Research Institute of Harbin Institute of Technology is the earliest scientific research institution to develop wall-climbing robots. Its representative wall-climbing robot is the multi-functional wall-climbing robot which was used to detect spray of thank surface [2]. In addition, other domestic universities such as Tsinghua University, Shanghai Jiaotong University, Southeast University, Dalian Maritime University and Ningbo University are developing wall-climbing robots, but their application scenarios are different [3].

Designing a robot requires two parts: mechanical structure and control system. The wall-climbing robots involved in this research are mainly used for tank detection. They stick on the tank surface by permanent magnets and move by two motors. The main difficulty lies in the robustness of the control system. Its control system should have certain decision-making ability. The system should interact fast with the user by analyzing environmental variables. And to complete the detection task, the robot have to equip detection sensor. This paper mainly introduces the hardware of the control system and the implementation of the software system. Based on the industrial computer, vision sensor, attitude sensor and high-precision odometer, the robot has the following characters: stable operation, and multi-platform control terminal based on Qt5.0 and Android 3.0.

2. Demand Analysis
Detection requirements: The robot should move stably on the vertical wall surface and can detect the wall surface temperature, wall obstacles and the posture of the robot body etc.

Communication requirements: The robot body control system roles as server and the remote control device do as client. They can transmit images and control commands to each other at the same
time. In addition, the picture transmission delay should be within 0.3s. The communication error rate between the server and the client should be less than 0.1%.

Interaction requirements: The operator can remotely control the robot, including setting the motion mode of the robot, setting the speed of the robot, setting the detection task of the robot, etc. The client can directly monitor the state of the robot.

Safety requirements: The robot needs to realize self-detection of battery power and low battery alarm, high temperature alarm and so on.

3. Climbing Robot Hardware System Design
The hardware system is the basic platform of the robot. A reliable hardware system can greatly improve the stability of the robot [4-5]. When designed the hardware system, we used the modular-design-idea in this study. The hardware part of the system mainly includes a power module, a controller module, a sensor module, a communication module, and a motion module. The overall design of the hardware system is shown in Figure 1.

![Figure 1. Overall design of the hardware system](image)

4. Climbing Robot Software System Design
The robot software system includes a control system of the body and a remote control system. It uses the C/S architecture and the MVC design pattern. The body control system is used as the server, and the remote control system is used as the client. It realizes login of multiple clients at the same time. In the MVC mode, the M layer represents the data layer (Model), which mainly includes sensor data and robot state information. C is a control layer (Controller) mainly responsible for the implementation of control algorithm, data forwarding, real-time alarm, client management and the like. V is the View layer, which is responsible for realizing interaction with the user and real-time data image display [6-7]. The functions of MVC are as shown in Figure 2.
4.1. Body Software System Design

The server is implemented by multi-threading technology, and the program includes 1 main thread and 4 sub-threads. It transfers data between threads by using shared memory. In addition, this system also used instruction buffer queue which all threads share. When the control instruction is received, the instruction is stored in the instruction queue. And when the instruction is completed, the instruction is deleted from the instruction queue. If the instruction queue is empty for a long time, some threads change to the sleep mode, and release occupied CPU resources to increase CPU usage. The instruction queue structure is shown in Figure 3. The instruction is inserted from the end of the queue, taken from the header, and the queue has a counter and a timer. The timer is activated when the counter is 0, and the thread is closed when the timer expires [8]. Figure 4 is a flow chart of the operation of the queue.

The main thread mainly execute initialization of global objects, opening and closing of sub-threads, maintenance of server-side UI, motion control of the body, and detection of motion control. The main thread program flow chart is shown in Figure 5.

The first child thread is a socket thread that responsible for client login and logout, socket communication, data encoding and decoding, and outgoing storage.

The second sub-thread is the sensor data acquisition thread that responsible for sensor data acquisition and storage.

The third thread is the image acquisition and transmission thread, which is mainly responsible for the login and exit of the camera, image acquisition and forwarding.

The fourth thread is the data processing thread, which is mainly responsible for processing the data and images fed back by the sensor, correcting the data, detecting the posture, and alarming the signal.
4.2. Client Software Design
The main task of the robot control is to complete the interaction between the control system and the operator, so a good user experience is required. In order to support multi-platform manipulation, the client has designed the PC version and the Android version respectively.

![Block diagram of the main thread](image)

**Figure 5.** Block diagram of the main thread

4.2.1. Windows/Linux control software design
The design of both Windows and Linux clients is based on Qt 5.0. Qt is cross-platform IDE, that is, when the source code was written on a platform, the source code can be compiled on the another platform and can be run without rewriting [9]. The design idea of client is still thread-oriented. Different threads complete different tasks. The designed client is shown in Figure 6. Real-time data for all sensors is displayed in the interface. At the same time, image display and robot movement control are also realized.

![Windows, Linux Client](image)

**Figure 6.** Windows, Linux Client
4.2.2. Android control App design

The Android client is based on Android Studio 3.0. Clients can run on Android tablets, Android phones, and Android emulators. These devices are easy to carry, and the interface interaction designed by Android Studio is closer to the user's usage habits than Windows, and it is more convenient to carry[10]. The Android client design interface is shown in Figure 7.

![Figure 7. Android Control App](image)

Click the SetNet button to enter the interface for setting up a network connection. The left side of the interface displays real-time data from the sensor. The circle in the lower left corner of the interface is the robot movement control area. The WIFI logo and battery logo at the top of the interface indicate the robot network connection status and current power. The exclamation point on the right side will be red when the robot is down or there is a dangerous situation. When an error occurs in the robot body program, the red color on the right side displays different colors depending on the error code. Flashlight logo is the robot LED switch. The gray dot control is a custom multi-function switch. Its operating gesture is to slide to the edge of the control to release. Therefore, the component can control the two sets of switches.

5. Test

In order to verify the feasibility and robustness of the system, the wall-climbing robot SEU_CLIMB_ROB_1 robot was used as the platform to implement the actual operation test and the system test. Figure 8 is a test view of the wall-climbing robot moving on a vertical wall. The state information and sensor data of the robot are displayed through the host computer. Figure 9 shows the real-time sensor data and status information of the robot. In the experiment, the sensor and communication part can transmit data stably. Redundant design idea have been used, for example both wireless and wired transmission methods are used.

![Figure 8. Robot Test](image)

![Figure 9. Sensor Data Display](image)

6. Conclusion

This study designed a complete control system for the wall-climbing robot applied to the detection of tank equipment. The designed system includes hardware system and software system. Combined with
modular design ideas and MVC design patterns, the system hierarchy is clear. The hardware system consists of multiple modules. In addition to the power module, each module can work independently, which greatly reduces the coupling of the hardware system, thus reducing the risk of robot downtime. The software part adopts the C/S model, the robot body roles as the server, which realizes the control of the robot; the remote device is used as the client to complete the interaction and monitoring with the user. The experimental results show that the control system can stably control the movement of the wall-climbing robot. Through long-term operation and repeated experiments, the stability and robustness of the control system are verified, which can meet the control requirements of the wall-climbing robot for tank equipment detection. In general, the system has strong robustness, low coupling. However, the system still has space for improvement and optimization. For example, the internal space of the robot is extremely small, and the internal heat of the machine is difficult to dissipate and high cost and other issues.

7. References
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