Design of A Three-DOF Redundantly Driven Parallel Robot Control System

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Abstract—Parallel robot has advantages of no friction and clearance, fast response, compact structure, good rigidity, and low error accumulation, but they also have many shortcomings in geometric characteristics, such as small range of motion, poor flexibility, and singularity in the workspace. Adding redundancy can improve its geometric characteristics. Parallel robots are usually controlled by dedicated controllers, without openness, high development costs, and long cycles. This paper introduces the design of an open control system for a three-DOF redundant drive robot based on PC bus, and with "PC + motion control card" as the core.

1. INTRODUCTION
Parallel robots have the advantages of simple structure, high motion accuracy, fast speed, and large load. They have been widely used in many industrial fields in recent years\cite{1-2}. The parallel robot control system is a very typical multi-degree-of-freedom real-time motion control system. The design of the control system will directly determine the performance of the entire robot system\cite{3}. At present, the hardware structure of open control systems mainly has two categories: systems based on VME (Versa Module Eurocard) bus and systems based on PC bus. The VME bus-based control systems are widely used in industrial control, military systems, aerospace, transportation, and medical fields, but the cost of such control systems is too high. PC has the advantages of low cost, openness, complete software development environment, and good communication functions. Design and developers can choose appropriate software and hardware module units according to needs, and realize high-performance robot control systems at low cost. The PC-based open controller facilitates standardization, networking, and digitalization and decentralization of servo drive technology\cite{4}. From the perspective of application,
this paper uses PC + motion control card as the core to build a control system platform with three degrees of freedom redundant drive parallel robot.

2. PARALLEL ROBOT BODY
The body of the parallel robot is shown in Figure 1. The robot is mainly composed of four parts: a work table, a link arm, an electromagnet pen holder, and a drive unit. Three pairs of link arms and their driving motors are installed on the work table. Each pair of link arms is composed of a driving rod and a driven rod. The length of the driving rod is the same as the length of the driven rod. The driving rod is driven by a corresponding driving motor. The driven rod and the driving rod are connected by an adjusting sleeve. The driven rod drives the electromagnet pen holder to achieve three degrees of freedom.

![Figure 1 Three-degree-of-freedom redundant drive parallel robot](image)

3. CONTROL SYSTEM DESIGN
The three-degree-of-freedom redundant-drive parallel robot adopted an open control structure of "PC + motion control card". The controller was based on a standard bus structure and had multi-axis synchronous high-speed motion planning functions. The dedicated CPU and PC CPU on the motion control card constitute a master-slave dual CPU control mode. The PC focused on system management tasks such as human-computer interaction interface, real-time monitoring, and sending instructions. The motion control card was responsible for motion control, discrete control, and housekeeping. And interact with PC, etc., without occupying PC resources. At the same time, the motion control card also provides a motion function library that can realize S-type and T-type curve acceleration, linear interpolation and circular interpolation, and multi-axis linkage functions.

3.1. Control system hardware composition
The hardware of the robot control system mainly includes the following parts: PC, GE-400-PV (four-axis) motion control card, terminal board, MELSERVO-J2S AC servo driver, HG-KN23J-S100 AC servo motor, position switch, proximity sensor and some other control circuits, the control system architecture is shown in Figure 2.
The entire control system uses a universal PC and a motion control card as the control center to perform servo control and some switching control. The PC and the PCI motion control card form the host computer control unit. The motion control card is inserted in the PCI slot on the PC's motherboard.

3.2. Control system circuit design
The control circuit of the robot control system is mainly composed of a motion control card control circuit, a servo motor drive circuit, and a limit switch control circuit[5]. The schematic diagram of the control circuit is shown in Figure 3. The main control process is as follows: after closing the enable switch of the servo driver and setting the corresponding motion parameters of the control system, the PC controled the motion control card to send signals such as position commands to the servo driver, thereby controlling 3 servo motors to drive 3 sets of connecting rods Movement, coupled with the translation and up and down movement of the electromagnet pen holder. Among them, the motion control card can accepte the pulse signal feedback from the incremental encoder inside each servo motor, forming a semi-closed loop control system; limit switches are installed at both ends of the working stroke of the swing lever on each group of Prevent the motor rotation angle from overtravel, and realize the hard limit function.

The GE-400-PV motion control card needed to use together with the terminal board in the electrical control cabinet. Its interface is shown in Figure 4. The interface definition is shown in Table 1. The motor interface pin definition is shown in Table 2.
There are three control modes of MELSERVO-J2S AC servo drive: speed mode, position mode and torque mode. Because the three-degree-of-freedom redundant drive parallel robot system required high speed and acceleration, the system use speed mode (analog output). The parameter setting is shown in Table 3. After setting, use JOG mode (no load) to check whether the connection between the driver and the parallel robot body is correct.

| interface | Features |
|-----------|----------|
| CN1       | Motion control card connection interface |
| CN2       | Motion control card connection interface |
| CN4       | Free / spare |
| CN5       | 1st axis motor interface |
| CN6       | 2nd axis motor interface |
| CN7       | 3rd axis motor interface |
| CN8       | 4th axis motor interface |
| CN9       | Auxiliary encoder interface 1 |
| CN10      | Auxiliary encoder interface 2 |
| CN12      | Dedicated I/O signal input interface |
| CN13      | Universal I/O input interface |
| CN14      | Universal I/O input interface |

### Table 2 CN5, CN6, CN7, CN8 motor interface pin definitions

| Pin | signal | Description |
|-----|--------|-------------|
| 1   | OGNDE  | External power ground |
| 2   | ALM    | Drive alarm   |
| 3   | ENABLE | Drive allowed |
| 4   | A-     | Encoder input |
| 5   | B-     | Encoder input |
| 6   | C-     | Encoder input |
| 7   | +5V    | Power Output  |
|   |   |
|---|---|
| 8 | DAC | Analog output |
| 9 | DIR | Step direction output |
| 10 | GND | digital |
| 11 | PULSE- | Step pulse output |
| 12 | Keep | Keep |
| 13 | GND | digital |
| 14 | OVCC | +12 / +24V output |
| 15 | RESET | Drive alarm reset |
| 16 | Keep | Keep |
| 17 | A+ | Encoder input |
| 18 | B+ | Encoder input |
| 19 | C+ | Encoder input |
| 20 | GND | digital |
| 21 | GND | digital |
| 22 | DIR- | Step direction output |
| 23 | PULSE+ | Step pulse output |
| 24 | GND | digital |
| 25 | Keep | Keep |

Table 3 MELSERVO-J2S AC servo drive parameter setting

| parameter | value | significance |
|-----------|-------|--------------|
| PA01      | 1002  | Speed mode   |
| PD01      | 0C00  | External enable |
| PA09      | 16    | Motor stiffness coefficient |
| PA13      | 0011  | Pulse + direction |
| PA15      | 10000 | Number of encoder lines |
| PC14      | 000E  | Voltage value display |
| PC20      | 1/2/3 | Site settings |
| PD26      | 0007  | Without brake |

The wiring diagram of MELSERVO-J2S AC servo driver and GE-400-PV motion control card speed mode is shown in Figure 5, with the first axis (CN5) as reference.
• Electrical control cabinet

Design the electrical control cabinet according to the control system and wiring diagram, as shown in Figure 6. Motion control card wiring terminal board, servo driver, switching power supply module, and other electrical components such as switches, relays, contactors, indicator lights are installed in the electrical control cabinet. An emergency stop switch is installed outside the electrical control cabinet. The front panel of the electrical control cabinet is equipped with the system power indicator, driver power indicator, and emergency stop button.

This control system platform has the characteristics of openness. After the user is set up, he can independently design software to control the redundant-driven parallel robot, which is not repeated here.

4. Conclusion

In this paper a design scheme of an open control system for a redundantly driven parallel robot is introduced. Users can independently design software for controlling a redundantly driven parallel robot. This system uses PC + motion control card as the core. Its hardware includes: PC, GE-400-PV (four-axis) motion control card, terminal board, MELSERVO-J2S AC servo driver, HG-KN23J-S100 AC servo Motors, limit switches, proximity sensors, and other control circuits. Design parameters for motion control card and terminal board, and servo drives are also described. The control system has the
characteristics of compactness, easy implementation, high accuracy, simple operation and openness, etc., and has high application value.

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