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Design of the 4-DOF Parallel Robot Control System Based on EtherCAT

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Abstract. This design includes both the hardware system and software system. The control system can not only achieve the motion control but also can realize simulation. Hardware system is constituted by Parallel Robot Body, Embedded IPC (Industrial Personal Computer), servo drive and motor system, EtherCAT module and I/O module and so on. Software system realized by the Automation software CODESYS, which including motion control program and simulation module. The experiment and program result showed that the system is working well, practice and reliable.

Introduction

With the development of science and technology, industrial automation has been the rapid promotion, of course put forward higher quality on the control requirements. The traditional automatic control using hard wired mode through PLC and relays and other devise, which brings the problem is complex and inflexible. This prompted the production of industrial filedbus. At present, industrial filedbus has been widely used, such as industry, agriculture and so on. EtherCAT is developed by Beckhoff Automation GmbH, which has been widely used due to it's opening. Also its has a lot of advantage such as high-speed, real-time, topology structure of flexibility etc.

Based on the advantages of EtherCAT, the design of 4-DOF(Degree of Freedom) parallel robot control system is developed based on the fieldbus. The detailed implementation of the system, including hardware design and software design. Hardware part is based on parallel robot body and sanyoDenki servo drive and motor system. Software part is the control system which is designed in CODESYS, which is developed by 3S.GmbH,Germany.

Hardware Design

Body Structure Design. The Fig. 1 shown is the body of the Robot, as it show, it including by Static platform, Upper arm, Low arm, Dynamic platform and Servo motor and so on. The static platform and the upper arm are connected by a rotary pair, the upper arm and the lower arm, and the lower arm and the dynamic platform are connected by a spherical joint. Such institutions have many advantages, such as flexible movement, fast speed and so on. When 3 servo motor in the rotation, the dynamic platform can be coupled out of three directions (X direction, Y direction, Z direction). In addition to the three direction, there is an universal joint connecting rod in the middle of this system, realize the dynamic platform's rotation in the vertical direction. As the rod 4 shown in Fig. 1.

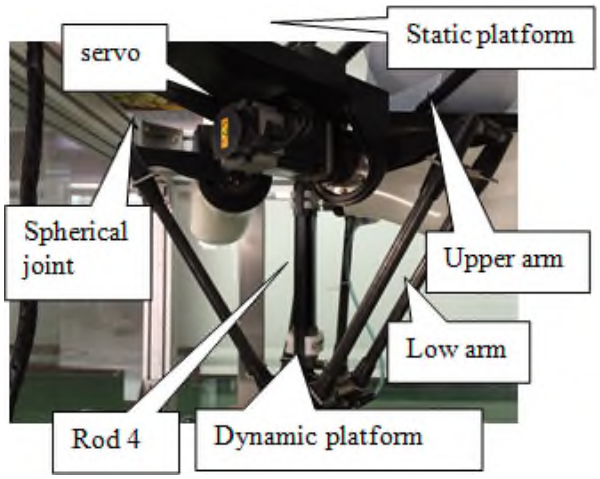

Fig. 1 The body of the Robot.

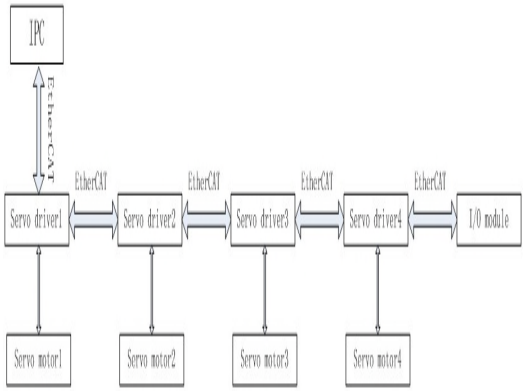

Fig. 2 The system's structure diagram.

The System's Hard Structure

The Robot control system hardware mainly includes: IPC (window7 operating system), sanyoDenki servo drive support by EtherCAT protocol and motor system, EtherCAT module, I/O module and the necessary circus. The control system's block diagram is shown in Fig. 2. The whole system used a embedded IPC which is operating WES7 (Windows Embedded Standard 7) system, Master station and slave link through the 100-BaseT standard and cross network cable to achieve control of the driver and the I/O module through the EtherCAT filedbus. From Fig. 2 we can see that the whole system connected in series, making the system wiring is simple and can be arbitrarily based on the need, to increase or decrease the number of control axis or I/O devices.

This control system is based on the EtherCAT fieldbus, to avoid the traditional control system's complexity of the line, so that the control cabinet is more concise, the line is more simple. As shown in the Fig. 4, the control cabinet design and the final physical map. Electrical control cabinet mainly includes: controller, four servo motor drives, I/O module, transformer etc.. The wiring of the electric appliance only needs to connect the circuit between the driver and the motor. And the controller and the driver, driver and driver, driver and I/O module only through the common network line (UTP) serial connection, saves the massive manpower and the material resources.

The main control process is that the robot control program operating in the controller (IPC), through the EtherCAT filedbus to transmit a signal to a first driver, and then the first driver sends data to the second driver, third, fourth, after then the fourth driver sends data to the I/O module. After processing the data back to the controller (IPC) in reverse order .

Control cabinet and control circuit wiring diagram as shown in Fig. 3.

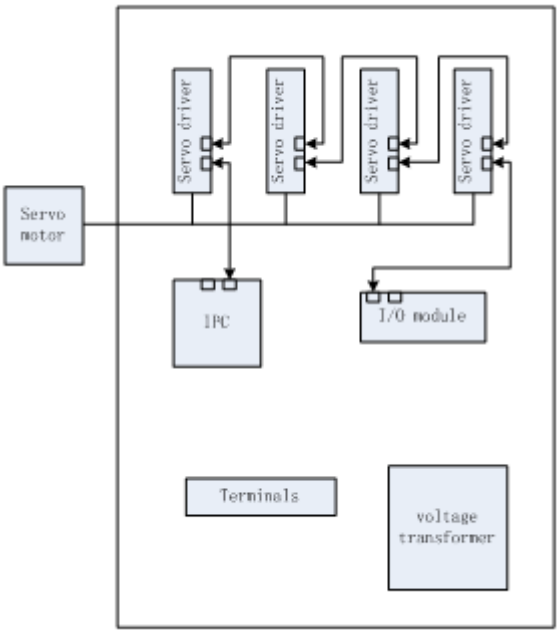

Fig. 3 Control system structure.

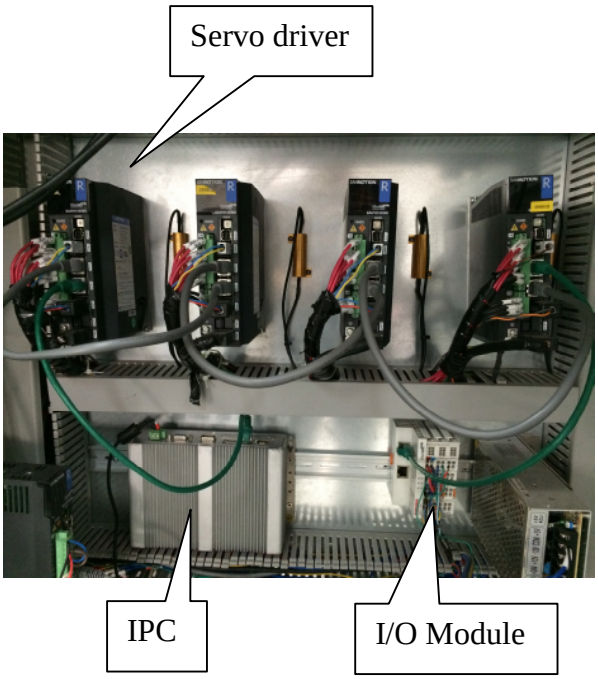

Fig. 4 Final physical map

Software Design

The 4-DOF Parallel Robot's control program is based on the opening software CODESYS. Which is Running on the Windows system. Codesys is a powerful software programming tool, which is developed by 3S.GmbH. It supports IEC61131-3 standard, including IL, ST, FBD, LD, CFC and SFC six PLC programming languages, It includes 3 parts: CodesysIDE (Interface Development Environment), Codesys Gateway, Codesys RTE(Run Time Environment). IDE is environment. Gateway is the bridge that connect IDE with RTE. Through it we can downloaded the program to RTE. It's also the necessary part of the system. RTE is a real-time inner-core which can running many operating system, such as WinXP or Win7.

This control system's Flow chart is shown in Fig. 5. From this chart we can see that this program's function mainly include Initial, Enable, Homing 3 motion model and system's Reset.

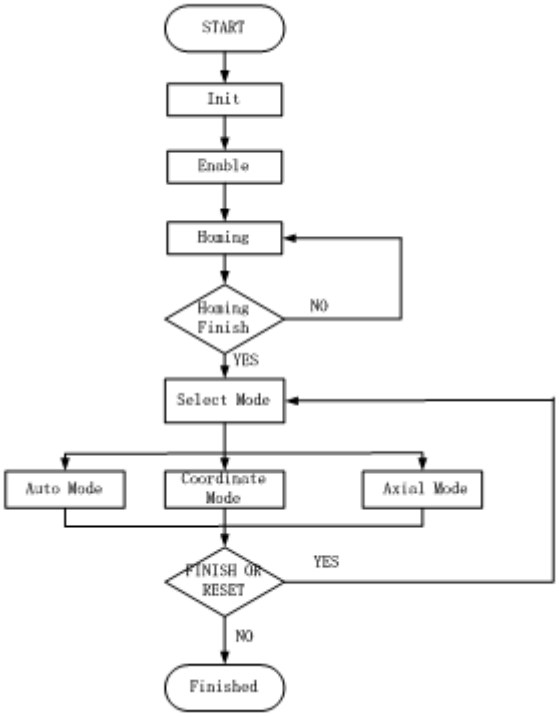

Fig. 5 The Flow Chart of the Program.

As mentioned above, CodesysIDE supported six PLC programming languages. So we can use anyone in our control system. The Fig. 6 shown the mainly structure of the control program, which is used the SFC (Sequential Function Chart) language. It looks more straightforward. Also we can monitor the program's dynamic state in time. Each block instead of one step, we can used anyone language of six to write codes. In follow I will take two examples to analysis the method of Programming.

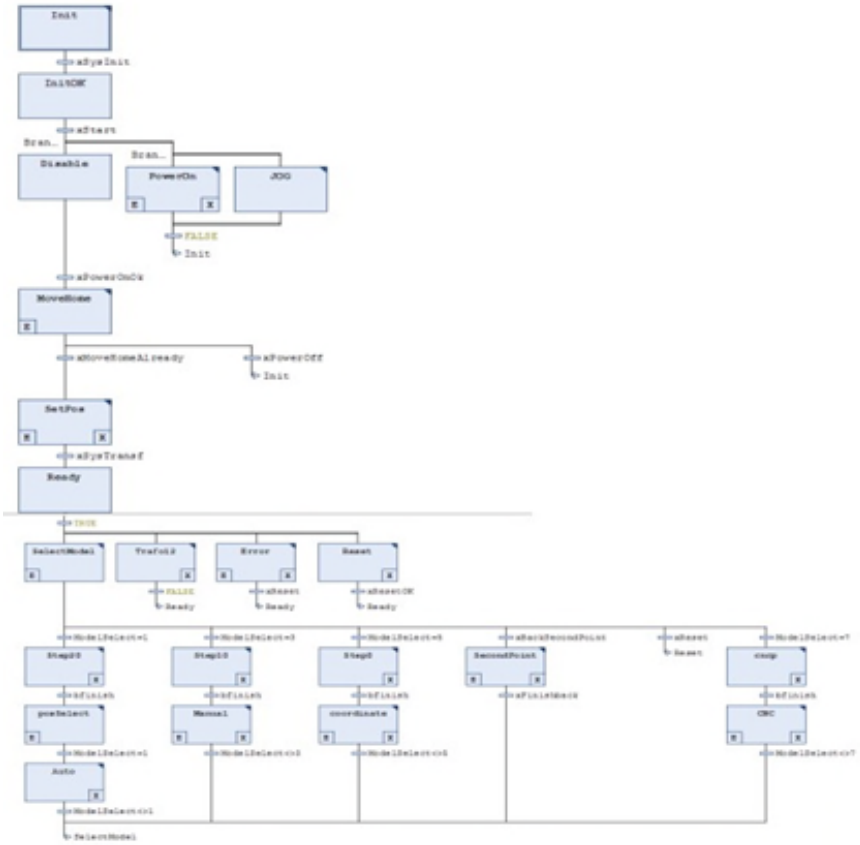

Fig. 6 The structure of the control program

The first example is the output of axis control as shown in the Fig. 7. In this step is made by CFC (Continue Function Chart) to finish the action. This part's function is drive the motor rotation base on the given position. The SMC_TRAFO_Tripod_Arm is the module which is this kind of parallel Robot's Inverse kinematic solution. It's input is the anticipating position by users. After the transformation of coordinate inside this module, the position of each motor's position (dA,dB and dC) give out to the module of SMC_ControlAxisByPos. This module is to drive the shaft rotation base on the calculated position. In this module, we can set some variable such as Velocity and Acceleration based on user's need.

The second example is Axis Mode as shown in the Fig. 8. In this step used the ST language. This language is similar with the C language. It makes program more logical. The step's function is very sample, finished shaft's Single step control which means weather motion or not based on human's command. We also can setting some variable such as Velocity and Acceleration based on user's need.

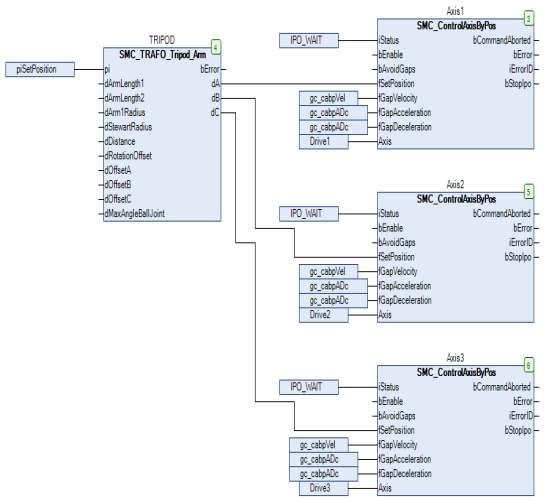

Fig. 7 The CFC of Moving By position.

```
jogx(
    JogPos:=g_xVisuAX1PLUS ,
    JogNeg:=g_xVisuAX1MINUS ,
    Velocity := g_lrVelocityMCS_Jog ,
    Acceleration := g_lrAccelerationMCS_Jog,
    Deceleration := g_lrDecelerationMCS_Jog,
    Axis:=drive1 );
jogy(
    JogPos:=g_xVisuAX2PLUS ,
    JogNeg:=g_xVisuAX2MINUS ,
    Velocity := g_lrVelocityMCS_Jog ,
    Acceleration := g_lrAccelerationMCS_Jog,
    Deceleration := g_lrDecelerationMCS_Jog,
    Axis:=drive2 );
jogz(
    JogPos:=g_xVisuAX3PLUS ,
    JogNeg:=g_xVisuAX3MINUS ,
    Velocity := g_lrVelocityMCS_Jog,
    Acceleration := g_lrAccelerationMCS_Jog,
    Deceleration := g_lrDecelerationMCS_Jog,
    Axis:=drive3 );
jogRZ(
    JogPos:=g_xVisuAX3PLUS ,
    JogNeg:=g_xVisuAX3MINUS ,
    Velocity := g_lrVelocityMCS_Jog,
    Acceleration := g_lrAccelerationMCS_Jog,
    Deceleration := g_lrDecelerationMCS_Jog,
    Axis:=drive4 );
```

Fig. 8 The ST of Moving By Jog.

The Visualization of System

In the HIM aspect, Codesys provided a similar style with MFC's controls for users and some motion control simulation. Users can do secondary development as their own needs. The simulation user interface of the system is shown in Fig. 9. The left side is a movable virtual model of the Delta structure which can simulate the motion according to the users input, and the right side is the control button, users can control the system through these buttons according to textual description.

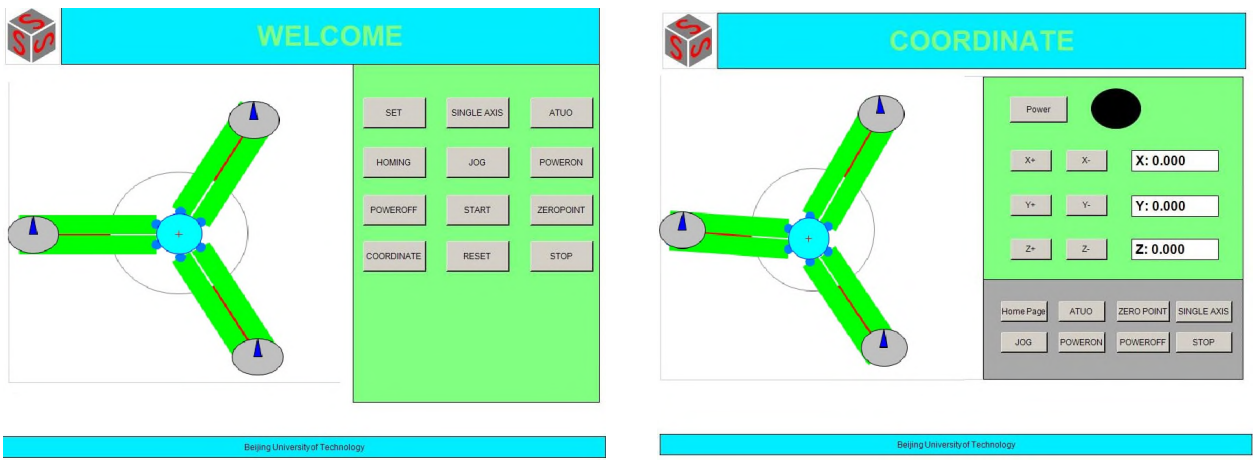

Fig. 9 The Visualization.

Summary

The whole system uses the open programming Automation software CODESYS. The design is simple, smart and based on the industrial filed-bus EtherCAT that meeting the requirements of industrial Robot's real-time. Developed a simulation user interface that is a convenient and intuitive interface. It give a good example to develop this control model and can bring to a large improvement in industrial automation.

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