Design of the Control System of 2-DOF Parallel Manipulator Based on CoDeSys

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Abstract: The 2-DOF parallel manipulator takes a parallelogram construction which can make its workbench always remain stable. Now it is widely used in various industrial sites. In consideration of the construction features and the control demands of 2-DOF parallel manipulator, this paper mainly introduces the motion control scheme and man-machine interface design of the manipulator. Based on the motion control programming platform of CoDeSys, the motion control and simulation debugging of the 2-DOF parallel manipulator are realized.

Key words: CoDeSys; two degree of freedom parallel manipulator; servo control

1.Introduction

The manipulators are widely required in the light industries fields such as food, electronics and medicine. They can implement all kinds of operations like carrying, sorting, loading and unloading of some light materials in short or medium distance . The parallel manipulator was used with serial mechanism for contrast. We can find that it is provides with many advantages, such as low load ratio, high stiffness and strong bearing capacity and so forth . Therefore, it is extensively used in various high-speed operation occasions. The Controller Development System is called CoDeSys for short. It is a sort of development environment for programmable logic controller which is developed by German 3S company. It is completely developed based on the IEC61131-3 standard . There are two kinds of languages in the controller development system. They are graphic programming languages and text programming languages respectively. Meanwhile, the soft PLC scheme has an open architecture, which makes it possible for many domestic and foreign manufacturers, such as ABB, Schneider, Beckhoff, Panasonic, Innovance, HCFA to develop their own programming software by the CoDeSys platform . In the past, there are various PLC programming platforms produced by different manufacturers. However, the unified programming platform of CoDeSys reduced the requirements for all users. When the developers use the PLC from different manufacturers, they can connect seamlessly and greatly reduce the time to familiar with programming software. So the control system for 2-DOF parallel manipulator developed in the environment of CoDeSys has higher universalities and practical values.

2.Brief introduction of 2-DOF parallel manipulator

As we can see in Figure 1, it is the plane graph of the 2-DOF parallel manipulator .The device is composed of a servo axis, a active arm, a slave arm and an actuating end. Two servo motors are set up on the stationary platform to drive the active arm, and the active arm is linked by the slave arm so as to control the end movement .

The manipulator with 2-DOF can move both vertically and horizontally on a two-dimensional plane from its initial position.

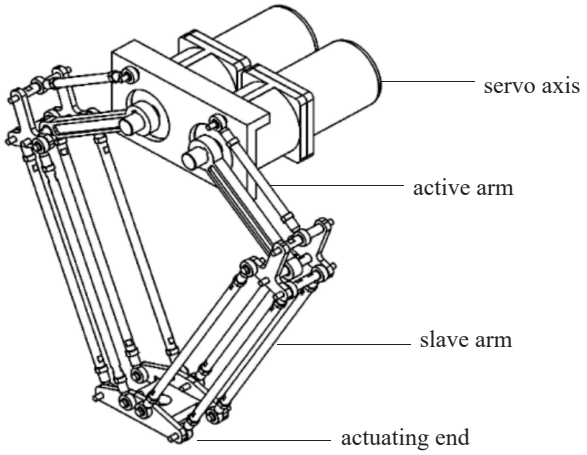

Figure 1.Mechanical structure design of 2-DOF parallel manipulator

3.Topology scheme of controller system

The manipulator control system is based on the CoDeSys programming platform and uses EtherCAT industrial bus to build a motion control network. We can see from Figure 2, the controller with CoDeSys is the control core in the whole system, which can realize some human-computer interaction operations such as system parameter configuration, system operation control, operation status monitoring by connecting HMI through ModbusTCP. Additionally, it can achieve accurate control of 2-axis servo motor via connecting the Panasonic servo

driver with the EtherCAT bus.

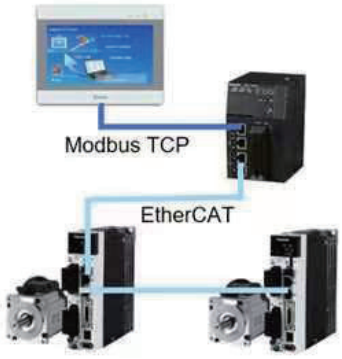

Figure 2. Topology scheme of controller system

4.Design for control system software

4.1 Object-oriented programming based on CoDeSys

The object-oriented is a sort of programming paradigm and can be used to develop software. It has its beginning with the application of computer advanced language used in programming. This programming thinking regards the relevant data and methods as a whole, and carries out system modeling from a higher level .

The class and object instance can be seen the elementary entities in the object-oriented programming. CoDeSys can regard the description of function block in program organization unit as the description of class, and each instance of function block is equal to the object of class. We can add the corresponding attributes and methods in the function block. When creating a function block, it can extend the other parent function blocks, or choose to implement an interface. In the meantime, we can control the access level of the functions, methods, and attributes through public, protected, private, and other access descriptors.

4.2 Software implementation based on CoDeSys function block

Based on the object-oriented programming idea, using the function block programming method provided in CoDeSys, the control program of the entire 2-DOF parallel manipulator is written in a function block. The control system of the 2-DOF parallel manipulator is changed from an independent control system to a reusable function block so that the universality of control system can be achieved, that is, the function block can be used in all PLCs using CoDeSys platform . It greatly simplifies the difficulty of use, increases the applicability, and reduces the use cost of customers.

The main software implementation process can be divided into function block design, main program design and simulation verification as follows.

4.2.1 Function block design

The function block of the 2-DOF parallel manipulator is mainly used to build the mathematical model for the 2-DOF parallel manipulator, calculate the corresponding servo axis angle of the end track according to the mathematical model, and control the servo motor to carry out the corresponding movement .

Input and output parameters of the function block

The input and output parameters of the function block are mainly used for the interaction between the function block and the outside . The role of the input parameters is to send control instructions from the outside to the inside of the function block and transfer the external parameters. The function of output parameters is to transfer parameters from the inside of the function block to the outside, such as operation status, error information, etc. Both the input parameters and output parameters are unidirectional. Another parameter category of the function block is input or output parameters. The parameters of this category are bidirectional. The parameters in this function block can be transferred from outside to inside, or from inside to outside. For example, the shaft parameters are the typical input or output parameters.

The interaction parameters of the function design are also divided into these three categories, namely, input or output parameters, input parameters and output parameters.

The input or output parameters are planned as two servo axis control parameters of the 2-DOF parallel manipulator. The input parameters include mechanical parameters and external control parameters of the manipulator. Output parameters include internal operation status, error information, etc.

Motion control of manipulator

According to the parameters of the manipulator input by the function block, such as the length of the active arm, the length of the slave arm, the distance between the two servo motors, the distance between the end actuators, etc., the mathematical model of the 2-DOF parallel manipulator is established. Through the method of inverse kinematics solution , the corresponding motor rotation angle is calculated according to the coordinate position of the center point at the end of the manipulator. The two servo axes are controlled to move through the synchronous motion command of the CoDeSys system so that the end effector can run to the set target position.

4.2.2 Main program design

The main program is mainly divided into two parts, one part is to interact with the prepared control function block of the 2-DOF

manipulator, the other part is to interact with the touch screen. The most important thing in interacting with the function block is to establish the actual axis in the main program as the control object of the function block. According to the structure of a 2-DOF parallel manipulator, it is necessary to establish two EtherCAT servo shafts in the CoDeSys project which can control the motion of the two active arms of the manipulator respectively, so as to drive the motion of the slave arm and make the executive end reach the set position. The interaction part between the main program and the touch screen mainly adopts the Modebus TCP protocol, which transfers the control instructions and various parameters of the touch screen to the PLC main program, and then transfers the main program to the 2-DOF manipulator control function block to complete the control of the entire system.

4.2.3 Simulation verification

CoDeSys system has powerful simulation function. Through the Trace function provided by the CoDeSys system, we can monitor the position, speed, torque and other information of the two servo axes in real time, as well as any variables in the program, such as the coordinate position of the end of the manipulator. If we put the above variable information into a Trace to monitor, we can easily see the angular relationship between the XY position of the end of the manipulator and the actual servo operation, so as to verify whether the entire control process is in line with expectations.

5.Design for man machine interface

The human-computer interaction part of the control system of the 2-DOF parallel manipulator is realized by the touch screen produced by Kinco. The main interface of the human-computer interaction is shown in Figure 3.

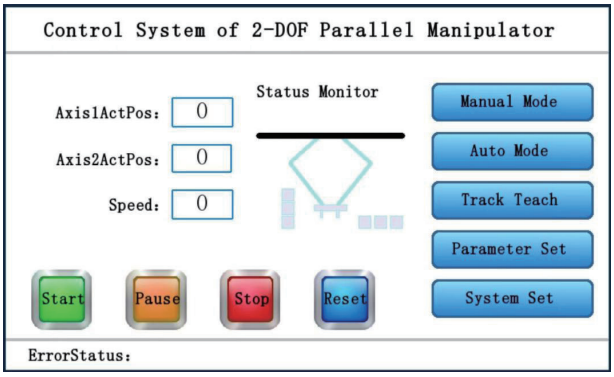

Figure 3. Man machine interface

It is divided into three parts: status monitoring, operation control and operation menu.

5.1 Status monitoring

Actual position of axis 1: It is used to monitor the actual angular position of the first servo axis of the 2-DOF parallel manipulator (For the 2-DOF parallel manipulator, the left servo axis is seen as the first servo axis).

Actual position of axis 2: It is used to monitor the actual angular position of the second servo axis of the 2-DOF parallel manipulator (For the 2-DOF parallel manipulator, the right servo axis is seen as the second servo axis).

Running speed: The running speed shows the running beat of the 2-DOF parallel manipulator, that is, how many grasping actions are completed per minute. The beat speed is related to the size, position, distance and the running track of the captured object, which presents a comprehensive speed.

Operation status monitoring: The operation status monitoring can monitor the picture of a graphical trajectory, which visually displays the operation trajectory and grasping status of the 2-DOF parallel manipulator in a WYSIWYG manner. As shown in the main interface of the touch screen, the left side is the object to be captured, and the right side is the position of the places object. Its operation logic is as follows: when the object to be grasped on the left side arrive at the location, the in place detection sensor will be triggered. After the controller system detects the in place signal, it will move from the waiting position according to the preset operation track to the grasping position and grasp the object. When the action of grasping the object is completed, the manipulator will move to the position where the object is placed according to the preset operation track. After the object is operated to specified location, it will release the gripper and place the object in place. When the action is completed, the manipulator returns to the waiting position and waits for the next capture signal. Then it will do such a cycle of action. With the help of this monitoring interface, we can visually observe whether the running track of the manipulator is in line with our expectations, whether the object arrival signal is triggered, and whether the object is carried away by the conveyor belt after placement. So we can easily observe the state of the whole system.

Alarm state: The alarm state displays the alarm conditions of the whole system so that the user can handle the abnormal problems of the control system according to the prompts of the alarm state. For example, servo alarm, communication alarm, sensor alarm, abnormal parameter setting alarm and other alarm information.

5.2 Operation control

Operation control is the main control part in the process of human-computer interaction, which controls the starting and stopping of the whole system through the middle button on the interface. It mainly includes the following parts.

Start: After the start button is pressed, the whole system is in operation, and corresponding actions will be performed according to the preset track and sensor signal.

Pause: When the pause button is pressed, the whole system will be in the pause state, the manipulator will hover at the current position, and the control system will record the current state. When the start button is pressed again, the pause state will be released, and the control system will return to the running state from the state before the pause.

Stop: After the stop button is pressed, the whole system will enter the stopped state, and the manipulator will return to the waiting position and will not respond to the external sensor signals. For added safety, the stop action of the manipulator is divided into several cases. The first case: the manipulator stops immediately without making any judgment, and all states return to the initial value. The second case: the manipulator stops immediately and then judges the current position and whether there is any object in the clamping claw. If there is some objects, it will keep the current state and run to the safe position for waiting. The third case: the manipulator will not stop immediately, and the manipulator will execute the stop action after the last cycle. The user can set the stop action in the system settings.

Reset: After the reset button is pressed, the system alarm, error, exception will be reset, and the control system will return to the initial state.

5.3 Operation menu

The function sub interface of the corresponding touch screen can be accessed through the operation menu.

Manual Mode: Under this operation sub interface, the whole system is in manual mode and it is mainly used for system debugging, maintenance, exception handling and other scenarios.

Automatic Mode: Under the operation sub interface of automatic mode, we can set automatic operation parameters such as track and beat.

Track Teaching: Under the operation sub interface of track teaching, the system running track can be determined by the way of system teaching, which will provide more convenient for users to set the running track of the manipulator.

Parameter Setting: The parameter information of the 2-DOF parallel manipulator can be set under the operation sub interface of parameter setting. It includes some mechanical information, such as the length of the active arm and the length of the follower arm. The control system will determine the operating angle of the servo motor through the inverse kinematics solution according to these parameter information.

System Settings: The operation sub interface of system settings is mainly used to set system time, alarm information display, operator permissions, stop mode and other parameters.

6.Conclusion

The 2-DOF parallel manipulator with the characteristics of high speed and light load has been extensively applied in many fields, such as food packaging, medicine, electronics and so on. In this article, we give the design of control system of 2-DOF manipulator, which is based on the controller development system. Meanwhile, the control requirements and control function of the control system are verified through data simulation and joint debugging.

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