Collaborative operation of 6-DOF industrial robot based on digital twin

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Abstract: In order to realize the collaborative operation between the physical prototype and the virtual prototype of industrial robot, a digital twin model of a six-degree-of-freedom industrial robot was established. The structure and motion parameters of the 6-DOF industrial robot are introduced. The virtual prototype model of the industrial robot was established based on Visual One; the digital twin modeling of the industrial robot was completed by the three methods communication between the virtual prototype of the industrial robot and the physical prototype was realized, and the virtual and real collaborative operation of the twin robot and the physical robot was realized. Experiments show that when manipulating the movement of the robot on the physical terminal, the digital twin was consistent with its behavior. The research results provide references for the application of digital twin technology in the field of industrial robots.

1. Introduction

Digital twin technology is a tool that integrates the physical world and the information world in the manufacturing industry to achieve barrier-free communication. Observe the state and behavior of physical entities to achieve control over the entire life cycle of physical entities. As an intelligent manufacturing carrier, industrial robots play an important role. After decades of development, it has been widely used in various fields and become the main equipment in the manufacturing process[1].

In recent years, the virtual debugging of industrial robots has been studied in China and abroad. Qi Ruolong of the University of Chinese Academy of Sciences, proposed a method for robot motion simulation and motion control based on the VC platform, through the software design module to complete the real-time communication between the various modules within the VC system[2]. Tian Biaoyu et al., implement an autonomous control scheme to evaluate the simulator to solve the path following problem of the Kuka robot arm[3]. In the process of simulating industrial robots, the above-mentioned scholars realized scene roaming and active human-machine interaction, but they still only stayed at unilateral interaction and failed to realize the equivalent mapping of the product in the information world to the physical world.

This paper aims to study the application of digital twins in industrial robots in the field of intelligent manufacturing, and explore three methods of using teaching programming, Works Process components, and Python scripts to establish digital twins and realize the communication between virtual prototypes of industrial robots and physical prototypes. The digital twin of the equipment can be used to realize the full life cycle process of the robot processing product when the process plan is formulated[4-6].
2. 6-DOF industrial robot structure and parameters

The six-degree-of-freedom industrial robot studied in this paper is Effort ER3A-C60. The effective load of the end effector is 3 Kg, the positioning accuracy is ±0.02mm, and it can complete product assembly, material handling, polishing, etc. The ER3A-C60 corresponding structural parameters are shown in Table 1. The robot's kinematic chain is composed of 6 joints, all of which are rotating joint. The rotation range of each joint is shown by $\theta_i$, and $d_i$ is the length of each manipulator.

| Robotic Arm | Length/cm | Joint Variables | Variable value range/(°) |
|-------------|-----------|-----------------|--------------------------|
| $d_0$       | 15        | $\theta_1$     | -167～167                |
| $d_1$       | 34        | $\theta_2$     | -130～90                 |
| $d_2$       | 5         | $\theta_3$     | -71～101                 |
| $d_3$       | 15        | $\theta_4$     | -180～180                |
| $d_4$       | 15        | $\theta_5$     | -23～203                 |
| $d_5$       | 8         | $\theta_6$     | -360～360                |

3. Digital twin modeling of 6-DOF industrial robot

3.1 Digital twin of industrial robot based on teaching programming

The teach pendant is the main tool for the operator to interact with the industrial robot. It can control the motion of each joint of the robot through jog, teach, direct programming, etc. and exchange data with the controller through the TCP/IP protocol to achieve the display of feedback information from the controller and the sending of interface data [7][8]. The controller performs corresponding motion control on the robot by receiving the signal sent by the operator.

The method of interpolation points is used in the teaching and programming of the robot, and the whole working process of the robot is decomposed. Each step of the movement and signal command is regarded as a program. The interpolation point method can more intuitively observe the robot's performance. The command signal for each movement and the next step, as shown in Figure 1.

![Fig. 1 Signal connection](image_url)

3.2 Digital twin of industrial robot based on Works Process

Based on Visual One, continuous job tasks are created and configured through process components in the work library. Works Process is used to set tasks to perform, to set and edit multiple tasks in the task
manager, and to perform in the order in the component property InserNewAfterLine. According to the step task of the robot grasping the product on the conveyor belt is added by the Process component in order to realize the robot grasping and complete the establishment of the digital twin, as shown in Figure 2.

3.3 Digital twin of industrial robot based on Python script
Calling Python scripts through Visual One can solve complex robot assembly and production line simulation. Python scripts are a wide-ranging digital twin construction method that can perform tasks for complex processes. For example, the scene robot constructs the realization of a digital twin of workpiece transportation on a round table, obtains the current component position through the "get application" function, and the "grab component" function realizes the robot captures the grasp of the workpiece, "linear movement" and "connected movement position" and other functions realize the positioning, movement path and trajectory planning of the workpiece. Finally, the construction of the digital twin of the industrial robot is completed based on the Python script, as shown in Figure 3.
4. Virtual and real collaboration of industrial robots with 6-DOF

4.1 Communication between virtual and real industrial robots
Time-sensitive data interaction is the basis for realizing the interaction between digital twin and physical entities. The communication between Visual One and ER3A-C60 robots is established. Compared with industrial data buses, Ethernet has significant advantages in transmission distance and transmission rate. It is compatible with protocols such as TCP/IP and Modbus TCP[10]. The interactive control software is used to configure the virtual and real signals required by the virtual debugging system, and the data and program logic of the industrial control equipment are verified by the digital twin.

Connect the ER3A-C60 robot and the computer to the same switch via industrial Ethernet, and then perform network diagnosis (Ping) on the device on the computer to check whether the robot and the computer are connected. Configure the corresponding target machine address and virtual and real interactive signals in the Kepware software, and complete the connection based on the digital twin signal interface. Connect through Kepware to check whether the IP and port settings are correct. After the connection is completed, start the PC port data collection, run the digital twin connection and data interaction, and complete the communication between the virtual port and the physical port of the industrial robot.

4.2 Virtual and actual collaborative experiments of industrial robots
Based on the completion of the communication between the robot and the PC and the data exchange between the physical port and the virtual port, a series of simple task operations are performed on the physical port of the robot, while viewing the behavior data and logical operation of the robot twin in Visual One, and observing the twin process execution tasks whether it is mapped to the physical port robot, if it does not execute according to the expected process path, immediately stop the acquisition, check the programming module and signal configuration corresponding to the error process, change and optimize it and re-run until the robot twin can complete the task as expected, to achieve the purpose of virtual mode, as shown in Figure 4.

Fig. 4 Virtual and real collaboration of ER3A-C60 robot

5. Conclusion
This article uses intelligent design methods to build a virtual prototype based on the ER3A-C60 robot, introduces three methods of teaching programming, Works Process components, and Python scripts to model the digital twin of industrial robots, and introduces the method of communication between the robot and the computer. The virtual and real collaborative operation of robots are completed. Digital twin technology will play a more important role in the optimization of robot use process and the digital management of the whole life cycle, providing a strong guarantee for the development of intelligent manufacturing in my country.
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