Journal of Artificial Intelligence Practice (2022)
Clausius Scientific Press, Canada
DOI: 10.23977/jaip.2022.050303
ISSN 2371-8412 Vol. 5 Num. 3

Hardware Design and Realization of the Motion Controller of Industrial Robot with Six Degrees of Freedom

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Keywords: Industrial Robot, Motion Controller, Hardware Design, Six Degrees of Freedom

Abstract: As intelligent manufacturing technology and advanced production equipment have attracted the attention of the world, industrial robots have become more and more standard weapons for intelligent production technology and advanced industrial equipment, and are at the center of the world's advanced production equipment technology. A key part of the industrial robot control system is the industrial robot management system, and its characteristics are crucial to the overall characteristics of the industrial robot. From a macro point of view, an industrial robot system can include two parts: a software system and a hardware device. The hardware device corresponds to the human brain, and the software corresponds to the design idea of the human brain. Therefore, if we want to improve the characteristics of the industrial robot system, we must start from the software core algorithm and design the hardware structure. This article studies the hardware of the motion controller of the six degrees of freedom industrial robot, and understands the related theory of the motion controller of the six degrees of freedom industrial robot based on the literature, and then designs the hardware of the motion controller of the six degrees of freedom industrial robot. The designed hardware system is tested, and the test result shows that the error of the controller designed in this paper is below 10%.

1. Inductions

The development of industrial robot technology so far, although there are many robot manufacturers and research institutions, there is no unified standard for the research and use of robot control systems [1-2]. With the increase in production demand and labor costs, the need for transformation and upgrading of traditional manufacturing has become increasingly urgent [3-4]. Industrial robots play a very important role in the development of manufacturing. In order to adapt to modern industrial production, robots must have greater flexibility and openness [5-6]. At the same time, they need to improve compatibility with various equipment in industrial production. Industrial robots can form an integrated control system with different equipment to cover different applications. In traditional control systems, users cannot embed their own control algorithms and cannot re-develop them. Therefore, the development of open control systems is the research focus of universities and research institutes at home and abroad [7-8].

Regarding the research on the movement controller, some researchers said that the traditional robot system on the market currently generally adopts the IPC+ motion control card architecture. This has the advantages of strong openness and convenient deployment environment, but most industrial computers are expensive, bulky, inconvenient to move, weak anti-interference ability, and are not suitable for actual working environments. In addition, most IPC machines rely on the Windows time-sharing operating system, but may not meet the requirements of system stability and real-time performance [9]. Some researchers have conducted research on the robot control system, showing that robot control technology has been widely used in industry for 30 years, and the traditional 6-degree industrial robot is a typical application. There are many different brands of hardware and software unit types in the world. In this case, it is difficult to integrate all software and hardware resources into a control system and make it compatible [10]. Some researchers also suggest that traditional closed robot control systems mostly adopt custom development methods. This has disadvantages that cannot be modified, including reduced system scalability, software reorganization capabilities, reduced system fault tolerance and reduced system network communication capabilities, which can no longer meet the growing economic needs, industrial robot control systems the openness is being favored by the market [11]. In summary, the research on the control system of robots has also attracted much attention, but how to improve the control performance of robots is an urgent problem to be solved.

This paper studies the hardware of the six-degree-of-freedom industrial robot motion controller. Based on the literature, it analyzes the problems of the six-degree-of-freedom industrial robot motion controller and the overall plan of the six-degree-of-freedom industrial robot motion controller hardware. The hardware of the six-degree-of-freedom industrial robot motion controller is designed, and the designed hardware is tested through experiments, and the effectiveness of the designed hardware is verified through the test results.

2. Research on Motion Controller of Industrial Robot with Six Degrees of Freedom

2.1 Problems of the Six-Degree-Of-Freedom Industrial Robot Motion Controller

(1) Low transparency

Robot controllers generally have specific functions and adapt to specific environments, but the closed functions of "dedicated computers, dedicated robot languages, and unique microprocessors" limit the expansion and improvement of the system.

(2) Low fault tolerance

Data association, communication and synchronization in parallel computing greatly reduce the tolerance of controller performance. The failure of one of the processors will completely crash the entire system.

(3) Low software independence

The processor hardware usually affects the architecture and logic architecture of the software system, so the software part of the robot controller cannot be transplanted between various systems.

(4) Low scalability

The controller structure is closed, and it is difficult to expand the system to meet other design requirements.

(5) Lack of network functions

Almost all robot controllers do not have network capabilities.

2.2 The overall Plan of the Hardware of the Six-Degree-Of-Freedom Industrial Robot Motion Controller

The main tasks of designing the robot motion control system in this task include communication, trajectory interference, speed planning, position control and system management. To determine the traffic control system designed in this article, the following factors need to be considered:

(1) The computing power of the motion control chip. Robot motion control includes three tasks: trajectory interference, speed planning and position control. Since the subject of this article is a six-axis industrial robot, computing multiple joints obviously consumes a lot of CPU time. Most importantly, position control is a very real-time task that directly affects the overall performance of the robot's motion. Combining intelligent control algorithms requires more advanced computing power on the chip.

(2) Communication method. The control system designed for this purpose requires continuous communication between the computer and the motion controller, high real-time requirements and a large amount of interactive data. The motion controller needs to receive real-time information about the position, velocity and acceleration of each joint from the PC orbiter. The computer needs to receive the current motion information of the joint from the motion controller.

(3) Hardware interface resources. This topic applies to multi-axis industrial robots. Take the most widely used 6-DOF industrial robot as an example. It requires 6 independent PWM motion signals, 6 rectangular coded feedback interfaces, 6 restricted positions and 6 directional duals. In addition, users should consider adding other sensors and modifying input and output interfaces for other purposes.

(4) CPU multitasking function. The robot-oriented motion controller determines that the command processing capability of the underlying processor needs to be very fast. In addition to basic position control tasks, there are also tasks such as communication, monitoring, and speed planning. It uses advanced software to complete the analog output of the position control algorithm in the position control cycle, complete other operations in idle time, and adjust the relationship between various tasks, so it needs to maximize the CPU utilization.

2.3 Control Algorithm

Traditional optimization techniques have accumulated rich experience in handling constraints. In order to solve the limitations of the multi-purpose model, this article will continue to use traditional processing methods. Converting restrictions to statement function items is an effective method.

The standard form of the multi-purpose model of the form is rewritten as:

$$\min F'(x, M) = f(x) - \sigma\tilde{F}(x) \tag{1}$$

In,

$$\tilde{F}(x) = \sum_{i=1}^{P}[\max(g_i(x), 0]^2 + \sum_{j=1}^{q}[h_j(x)]^2 \tag{2}$$

F(x) is called the penalty function. The parameter σ>0 is called the penalty factor. Obviously when it is $x \in \Omega$, F(x)=0; when it is $x \notin \Omega$, F(x)>0. Therefore, solving the multi-objective constraint problem is transformed into a zero-constraint problem of a new objective function with a penalty function term.

3. Hardware Design of the Six-Degree-Of-Freedom Industrial Robot Motion Controller

3.1 Design Overall Architecture

Taking into account the cost of the control system and all the above requirements, this article excludes the expensive "industrial computer + motion control card" solution, and adopts the dual CPU STM32+FPGA solution. Use STM32 to run faster, provide powerful data processing capabilities, advanced integration and convenient deployment. "STM32, as the main control chip, performs functions such as human-computer interaction, kinematics analysis, and motion planning. FPGA is the core of input and output, mainly external switch signals and encoder feedback, used to collect signals and pass them to STM32 after certain processing. STM32 sends out the corresponding pulse machine, the servo motor rotates, the whole framework of the hardware control system is shown as in Fig. 1.

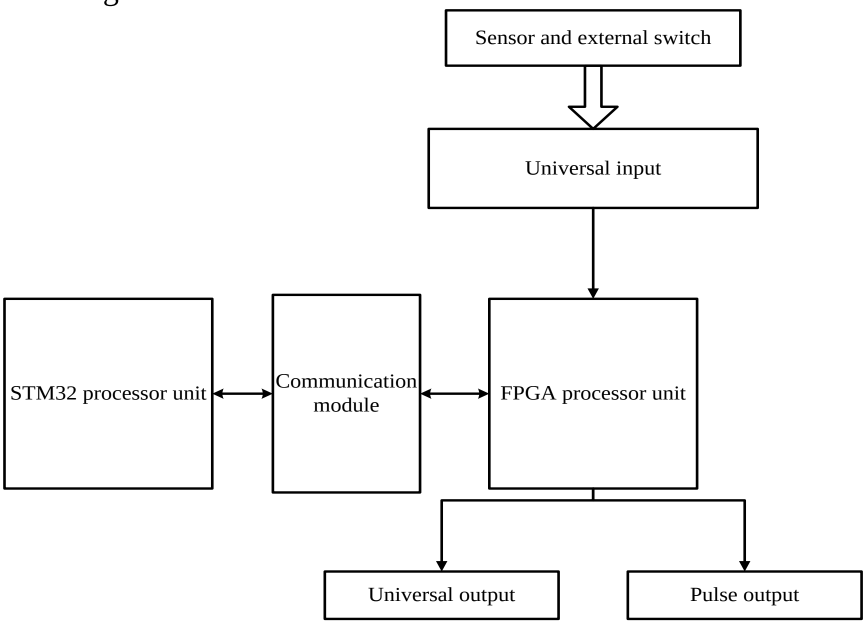

Figure 1: The entire frame diagram of the hardware control system

3.2 Chip Selection

Due to the rapid development of microelectronics technology and zero-point five-conductor device technology, especially with the significant advancement of digital signal processing technology and microelectronics company process technology, FPGA chips are also constantly updated and replaced, and their functions and logic resources are becoming increasingly powerful. The core and multiplexing technologies of various embedded process IP have also been developed more extensively. Developers can integrate microprocessors and multiple IP cores into FPGA core blocks, and use schematics or HDL logic language to create SOPC-based digital chip system technology industrial robots. In this subject, based on the above-mentioned characteristics of FPGA chips, we will learn more about the requirements of FPGA chips, the number of storage units and interfaces, and decide to use Altera EP3C16F484I7NFPGA chips.

3.3 Communication Method

The controller communication system is equipped with a standard network card and uses a real-time operating system as the basic software platform. According to the characteristics of the work department, in order to facilitate future research, the controller communication system uses two microprocessors for processing. As the microprocessor in the control algorithm part to be learned later, the microprocessor is mainly used for instruction interpretation, forward and reverse motion calculation, trajectory design, interpolation and speed control, etc. It is a communication interface module with teaching function, including units, robot motion library, etc. In this case, in addition to the research of the control algorithm and the development of the motion function library, the main tasks related to communication have been completed. The microprocessor responsible for communication with the server is transplanted to the EtherCAT protocol stack as the main communication station for communication with various steering gears. The unit and microprocessor responsible for the control algorithm, such as various hardware drive units, servo unit interconnection units, relocation of the EtherCAT protocol stack, etc. The two microprocessors exchange information at high speed through DPRAM.

3.4 Hardware Interface

The DMC2163 board has two signal interface boards. Each interface board has four motion feedback interfaces, an I/O signal interface and an auxiliary encoder interface. Since DMC2163 can only control 6 motion axes at a time, there are 6 motion feedback interfaces in total. The drive feedback interface is used to connect to the servo unit, and the I/O signal interface is used for I/O input and emergency stop interface. This system does not use the encoding utility interface.

(1) Connection between DMC and servo mechanism

The motion feedback interface of DMC is used to send signals between DMC and the servo mechanism, and the reverse interface of the servo mechanism unit is CN1. The wiring between DMC and steering gear is different for different control methods.

(2) DMC2163 jumper setting

After checking the servo system, it is necessary to set some jumpers on the DMC2163 board to ensure that the control system has the position control function. Set the NO.0 parameter of the servo motor unit, and the setting mode is position mode. The servo motor is currently in step mode. If DMC operates the axis in stepper motor mode, the corresponding step mode (SM) jumpers on the DMC board must be short-circuited, and each jumper is identified by SMX to SMW. For the corresponding software mode, the MT command must be used to set the corresponding axis mode to stepper motor mode. MT not only adjusts the operation mode, but also adjusts the type of output pulse. There are two types of output pulses: high efficiency (MT-2) and low efficiency (MT2). For safety reasons, the servo motor should be kept "off" when it is turned on. The engine can only be started after DMC has executed the "SH" command. The MO position of the cut jumper is next to the stepper motor jumper (SM).

4. Hardware Test

Table 1: Hardware test error results

	Error E1 (mm)	Error E2 (degrees)
Point 1	0.08	0.09
Point 2	0.081	0.06
Point 3	0.095	0.03
Point 4	0.09	0.032
Point 5	0.05	0.05

Randomly draw the end of the robot at any position in the workplace, record the point of the current position, and obtain the coordinate points of the five groups of robots in the common coordinate system and the rectangular coordinate system. The calculated error data is shown in Table 1:

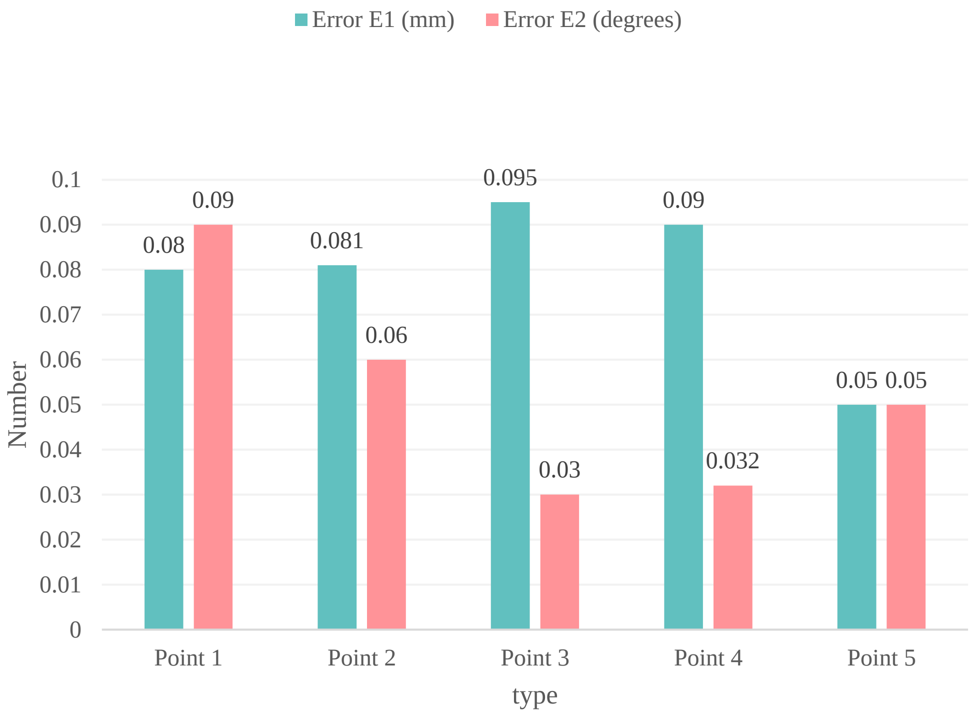

Figure 2: Hardware test error results

It can be seen from Figure 2 that the position control error of the controller is relatively small, the average value of the coordinate axis error is 0.08, and the angle error is 0.06, which basically meets the error requirements of the control system.

5. Conclusions

This paper studies the hardware of the motion controller of a six-degree-of-freedom industrial robot. After understanding the relevant theories, the hardware of the six-degree-of-freedom industrial robot motion controller is designed, and the designed hardware is tested. The test results are as follows: The average error of the coordinate axis of the controller designed in this paper is 0.08, and the angle error is 0.06, which basically meets the error requirements of the control system.

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