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Research on modular implementation method of six-degree-of-freedom robotic arm

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Abstract. Single-joint modular design can reduce the work intensity of designers, and also can broaden the combination form of multi-degree-of-freedom robotic arm. In order to adapt to the changes of multiple degrees of freedom and multiple loads, this paper designs a series of standard modules with similar components and the same standard interface, but with different sizes only, and chooses different drive components according to the load when designing the size, and then designs the size of other parts according to the size of the drive components. The final combination of this series of modules into different degrees of freedom robotic arm, such as three degrees of freedom robotic arm, four degrees of freedom robotic arm or even six degrees of freedom robotic arm. In this paper, the most widely used six-degree-of-freedom robotic arm is used as an example, and a detailed design form is proposed.

1. Introduction

In recent years, with the rapid development of manufacturing industry in China, industrial robot technology has also been developed rapidly, and the most common application of industrial robots is the six-degree-of-freedom robotic arm. According to the size of the load, robotic arms can be divided into three categories: large, medium and small. Large robotic arms are mainly used for heavy loads such as handling, palletizing, assembly. Small and medium-sized robotic arms are mainly used for welding, painting, testing and other occasions with smaller loads [1]. With the continuous development of foreign industrial robot technology, especially some small and medium-sized robots, they have the characteristics of small size, light quality, high precision and reliable control, and even developed a more lightweight control box, which can be moved at any time in the work area. This greatly facilitates the operation of staff, and China still has a gap in the research and application of such robots compared with industrialized countries, so it is especially necessary to research a similar robotic arm. Six-degree-of-freedom robotic arms are industrial robots composed of six rotating joints in series [2]. Most of the existing six-degree-of-freedom robotic arms in China are composed of joints in series of different designs, which not only increases the design difficulty and design intensity, leading to more production processes and time-consuming assembly, but also eventually the overall structure of the six-degree-of-freedom robotic arms connected by joints in series is complex, and the interchangeability of joints is limited. The overall structure of the final six-degree-of-freedom robot arm is complicated, and the interchangeability of joints is limited. When the robot arm work is easy to occur when the line entanglement problem, the light leads to line disconnection, motion accuracy is not allowed, the heavy leads to damage to the robot arm, more importantly, many joints do not have a power failure protection device, when the power suddenly cut off the robot arm can not quickly stop, thus endangering personal safety [3]. Due to the existence of the above-mentioned series of problems, making the design of the robot arm is very important, so to carry out research on modular joint technology.

2. Basic technical parameters of the six-degree-of-freedom robot arm

The technical parameters of the six-degree-of-freedom robot arm are more, among which the most basic ones are degrees of freedom, working space, payload, motion speed and motion accuracy.

2.1. Determination of degrees of freedom

Degrees of freedom are the number of independent coordinates an object has when it moves. Generally speaking, six degrees of freedom are required to describe the movement of an object in three-dimensional space, which are the movement and rotation around three coordinate axes. The degree of freedom of the robot arm is the independent motion parameter needed to determine the operating position of the actuator at the end of the arm, which can reflect the degree of flexibility of the robot arm movement. It is generally expressed in terms of the number of independent movements along the axis of movement and rotation around the axis (the degrees of freedom of the end-effector are not counted) [4]. Each joint has one kinematic sub, i.e., only one degree of freedom, so usually the number of degrees of freedom of a robotic arm is equal to the number of its joints. The robotic arm designed in this paper requires powerful functions and can generally complete more complex operations, so the number of degrees of freedom is set to six, and the six-degree-of-freedom robotic arm is more representative in the application of multi-degree-of-freedom robotic arm..

2.2. Determination of working space

The working space is the collection of spatial positions that the end-effector can reach according to certain conditions when the robotic arm is in motion. Since the shape and size of the end-effector vary greatly in design, in order to be able to truly reflect the parameters of the robotic arm, the general working space is the working area that the robotic arm can reach when the end-effector is not installed. Its shape and size are very important. When a robotic arm is performing a task, there may be a dead space that the hand fails to reach resulting in failure to complete the job. In the case of the arm in this paper, the maximum radius of gyration is tentatively set at 130cm because the task it is working on is not yet determined.

2.3. Determination of payload

Payload is the weight of the object that the end-effector can carry or the maximum force or torque that the end-effector can withstand when the robotic arm is in operation, and it indicates the size of the arm's load capacity. The load of a robotic arm does not only depend on the mass of the load, but is also influenced by the magnitude and direction of the acceleration and speed of the motion. In order for the robotic arm to work safely, the payload generally refers to the load of the robotic arm in the high-speed operation state. In this paper, the arm mainly completes the motion control and teaching reproduction functions, and the load requirement is not too high, so the payload of the arm is set to 10 kg for the time being.

2.4. Determination of motion speed

In order to achieve higher productivity, the operating speed of the robotic arm is required to be high, but in some work situations, the nature of the operation rather than the operating speed of the robotic arm itself determines the size of the speed. In addition, there is a big difference between the maximum speed of the robot arm end-effector and the overall cycle time. The motion cycle process generally includes an acceleration start phase, a uniform motion phase and a deceleration braking phase, and in order to ensure motion accuracy, a longer running time is usually provided in the acceleration start and deceleration braking phases, so it is also necessary to improve the acceleration and deceleration capability of the robot arm.

2.5. Determination of motion accuracy
The accuracy of the overall mechanical system of the robotic arm has three aspects, which are position accuracy, repeat position accuracy and system resolution. The maximum position error of the end-effector of the robotic arm is determined by the position accuracy and the repeat position accuracy. Position accuracy refers to the size of the positioning error of the end-effector of the robot arm, which is the size of the coordinate distance between the center of the curve formed by the actual arrival position of the end-effector and the target point. The repeat position accuracy is the width of the curve formed by the actual arrival position of the end-effector [5]. Generally, the repeat positioning accuracy of the robot arm is higher than the position accuracy, so the value provided in the product specification usually refers to the repeat positioning accuracy. There are many specific reasons affecting the accuracy of the robot arm, and the positioning accuracy here is tentatively formulated as ±2mm.

3. Six-degree-of-freedom robot arm solution selection

3.1. Structure form of robotic arm
We can classify robots into two types: articulated robots and non-articulated robots according to their structure. We can classify articulated robots into right-angle, cylindrical, spherical, and articulated robots according to their coordinate forms.

(1) Cartesian Coordinate Robot

The simplest form of the articulated robot is the Cartesian Coordinate Robot. As shown in Figure 1(L), three of the joints are actively moving joints (i.e., PPP-type joints), so there are a total of three degrees of freedom of movement, and the position of the end-effector is changed in space by the displacement of three mutually perpendicular coordinate axes. The right-angle coordinate robot has high positioning accuracy and its spatial trajectory is easy to calculate, but the mechanical body of the right-angle coordinate robot occupies the largest space volume among robots under the same working space conditions.

(2) Cylindrical Coordinate Robot

The cylindrical coordinate type robot has two degrees of freedom of movement and one degree of freedom of rotation, as shown in Figure 2. This type of robot accomplishes the change of spatial position of the end-effector by three degrees of freedom, and its control system is relatively simple and can avoid obstacles well. However, this robot is relatively large and has poor coordination performance when working with other types of robots, and it is complicated to design two moving axes.

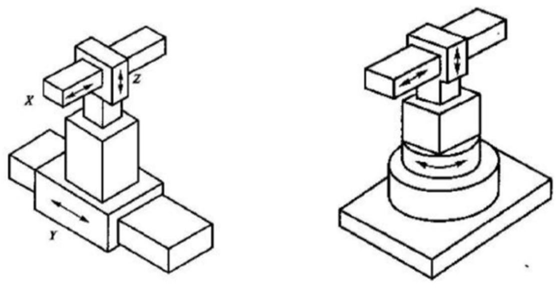

Figure 1. Cartesian and Cylindrical Coordinate Robots.

(3) Ball coordinate robot

The ball coordinate robot consists of one linear movement degree of freedom and two rotation degrees of freedom, as shown in Figure 2(L), i.e., translation of the arm along the X-axis direction, rotation around the Y-axis and rotation around the Z-axis. The robot occupies a small area, the overall structure is relatively compact, the position accuracy is OK, it can work in better coordination with other types of robots, it is light in weight, but the ability to avoid obstacles is poor, there are some problems in balance, and the length of the arm also directly affects the position error of the robot.

(4) Articulated Coordinate Robots

The articulated robot consists of a base, a large arm and a small arm. This is shown in Figure 2(R). The overall motion of the robot consists of the pitching motion of the large arm, the small arm and the slewing motion of the base. Its structure is the most compact among these four types of robots, and its motion is more flexible. However, its position accuracy is lower compared to other robots, it has certain problems in balancing, and the structure of the control system is more complicated. However, because it has a series of advantages mentioned above, most of the articulated coordinate type robots are used in practical applications.

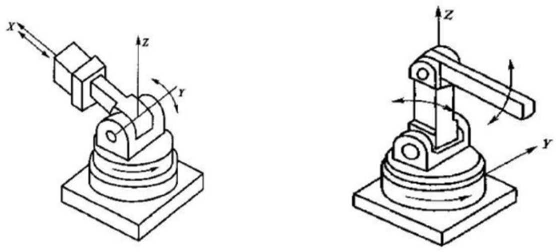

Figure 2. Spherical and Articulated Coordinate Robots.

3.2. Design solution of robot arm

Through the above analysis and research, it is initially determined that the six-degree-of-freedom robot arm adopts the joint coordinate type, and the six joints are composed of three joints of the base, large arm, small arm and wrist. Each joint adopts the transmission method of hollow servo motor driving hollow harmonic reducer. Mechanical arm independent design parts to ensure the premise of stiffness and strength, choose light, simple processing, cost-effective aluminum alloy material. The design requirements of the robot arm are: to reduce the mass of the parts as much as possible under the premise of certain safety factor, to maximize the load capacity of the robot arm, and the terminal load capacity is 10Kg.

At present, it is still convenient to solve the inverse kinematics for most six-degree-of-freedom tandem-type robotic arms, but to obtain the final displayed solution one of the following two sufficient conditions must be satisfied:

(1) The three adjacent joint axes intersect at a point;

(2) The three adjacent joint axes are parallel to each other.

The robotic arm designed in this paper satisfies the latter of the two sufficient conditions, i.e., the three adjacent joint axes are parallel. If the three adjacent joint axes are intersected at one point, the final configuration of the arm is difficult to see, and the degrees of freedom overlap more, and the posture of the arm receives a great restriction, while the working space of the arm designed in this paper is larger, and the degrees of freedom overlap less, and it can work in a variety of postures with higher flexibility, and its specific design form has the following four kinds, as shown in Figure 3.

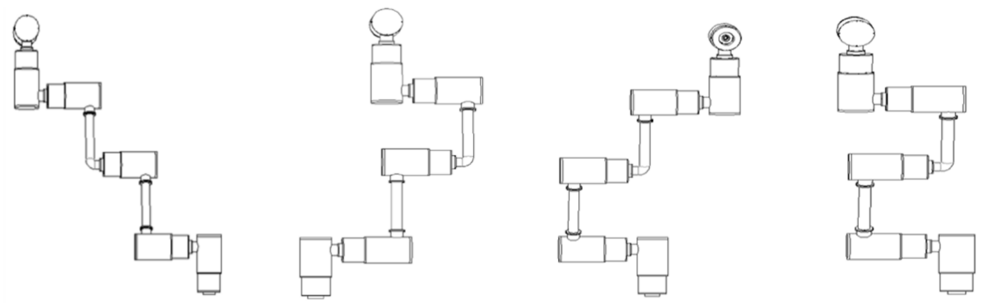

Figure 3. Four different forms of conformation (from left to right, 1, 2, 3, 4).

From the above four configurations, it can be seen that the first joint rotates in the vertical direction, the second, third and fourth joints rotate in the horizontal direction, the fifth joint rotates vertically in the fourth joint, and the sixth joint rotates vertically in the fifth joint. The fourth joint, the fifth joint and the sixth joint form a spatial right-angle coordinate system.

The above four configurations of the six-degree-of-freedom robotic arm have an important connection with the solution of the inverse kinematics, so the selection of the robotic arm configuration directly affects the difficulty of the derivation of the positive and negative kinematics of the robotic arm, and at the same time, it also has a certain relationship with the establishment of the coordinate system of the robotic arm. After comparing the above four different configurations, we finally choose configuration 4 as the overall solution of the arm.

4. Overall structure of six-degree-of-freedom robot arm

Due to the design of a series of modular joints with different power, load and size as well as connecting rods, these modular joints are connected in series according to the finalized configuration4 to finally form a six-degree-of-freedom robotic arm.

After the overall design of the robot arm is completed, its degrees of freedom are first verified. From the knowledge of mechanical principles, if there are n objects in the three-dimensional space that are not constrained at all, and we choose any one of them as a fixed reference, because each object is not constrained, so there are six degrees of freedom relative to the reference, then there are 6 (n-1) degrees of freedom for n objects [6]. If joints are connected in series by a link to form a robotic arm, assume that the binding force of the ith joint is u_i (i.e., the number of degrees of freedom of motion that can be constrained by that joint), and if the number of joints is g,then the number of degrees of freedom of that robotic arm is:

$$M = 6(n-1) - \sum_{i=1}^{g} u_i \tag{1}$$

The above equation is the formula for calculating the number of degrees of freedom of a mechanism moving in space in general form.

The arm designed in this paper has 7 rods, including the base, of which 6 are joints, and each joint has only one degree of freedom of rotation, so a total of 5 degrees of freedom are limited, and n=7, g=6, u_i=5 are substituted into the above equation to obtain the following results:

$$M = 6(7-1) - \sum_{i=1}^{6} 5 = 36 - 30 = 6 \tag{2}$$

5. Six degrees of freedom robot arm joint motor and reducer selection method

The load of the end-effector of the robotic arm is 10kg, considering that the load of the first joint is larger and the load of the sixth joint is smaller, the motor and reducer are initially selected based on the estimation of the torque and motor power of each joint. The selection of drive elements and transmission parts for each joint of the robot arm needs to refer to the power parameters of each joint. Based on the knowledge of robot dynamics, the robot dynamics equations are as follows:

$$Q = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + F(\dot{q}) + G(q) \tag{3}$$

Among them:

q --- joint position vector

$\dot{q}$ --- joint velocity vector

$\ddot{q}$ --- joint acceleration vector

M --- operational inertia tensor

C --- related to centripetal and Gauchy acceleration

F --- quantities related to viscous and Coulomb friction, also related to the direction of joint velocity

G --- inertial load

Q --- joint generalized force vector

Since the joint moments of the six-degree-of-freedom robotic arm are different, the moments are first estimated, then the motor and reducer selection is determined according to the moments, the joint dimensions are designed according to the selected motor and reducer dimensions, and finally the joints are connected in series to form a six-degree-of-freedom robotic arm to establish a model for kinematic analysis and dynamics simulation.

When designing a robotic arm, the methods for calculating its dynamic parameters are divided into two main categories: one is the static method, and the other is the kinetic method. When the rotational speed of the robotic arm is low, the dynamic load generated by the moving member under the action of inertia force is not large, so the effect of item C is small, and the value of friction is also relatively small and can be ignored, calling this method of calculating only static load a static calculation. When the rotation speed of the robot arm is higher, the dynamic load generated due to high-speed rotation is also relatively large, and the effect of C term is also very large, and generally will greatly exceed the other static loads, and viscous friction is proportional to the joint speed, said that this method that involves both static and dynamic loads for kinetic calculations. Since the six-degree-of-freedom robot arm needs to complete the motion control and teaching online functions, unlike the industrial robots used in general factories, the operating speed of each joint in the robot arm is relatively low, so the static method can be used to estimate the moment of each joint of the robot arm, and then determine the parameters of the drive and transmission components, and finally complete the selection of both.

In principle, the power of the selected motor should be greater than the calculated limit power, and a certain amount of margin should be left. The rated output torque of the selected reducer should be greater than the calculated limit torque of the joint. The rated torque of the motor multiplied by the reduction ratio of the harmonic reducer and then multiplied by the transmission efficiency should be greater than the calculated joint limit torque, and a certain amount of margin should be reserved.

6. Conclusion

In this paper, a six-degree-of-freedom robotic arm is designed based on modular joints. The modular joints are connected in series with standard mechanical interfaces to form a six-degree-of-freedom robot arm. These modular joints have the same structure, variable dimensions and standard interfaces. In the previous phase of work, the structural design of the modular joints has been basically completed, and the six-degree-of-freedom robotic arm has been assembled through the series connection of the modular joints, and the kinematics of the robotic arm has been analyzed to lay the theoretical foundation for the determination of the working space and trajectory planning.

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