Design and Realization of a Special Robot Manipulator

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Abstract. A structure of small special robot manipulator is designed by using the parallelogram lifting device. The stiffness and strength for the manipulator are both improved to meet indicators and functions of the performance by design and calculation. The grasping range of the manipulator is enlarged and the grasping force is enhanced by comparing different materials according to the simulation on Solidworks. The object can be grasped accurately by the manipulator. This kind of structure design provides a reference for a robot manipulator.

1. Introduction

With the development of robot research and the huge growth of various demands of robot, the application area and the concept of robot are expanded day by day. The special robot has been successfully developed on different area such as hazardous environment operation, ocean resource survey, nuclear power, space probe and military reconnaissance. Nowadays, the special robot has been a significant direction of mechanical and automation technology development.

The manipulator of robot, one of the key component, has also been greatly improved by the rapidly development of special robot. The manipulator is a highly integrated and intelligent electromechanical system, that is a last execution part with the sensors of the mutual interaction between robot and environment. The manipulator is applied in various areas and interdisciplines relating to mechanism, bionics, automation, computer science, artificial intelligence, microelectronics and materials. The important design indicators of the manipulator are grasping reliably, environmental adaptability, controlling simply and self-adapting.

2. The Research Status

Because of the important role of manipulator to the robot, various universal or special grippers have been developed by developed countries, such as the US, Germany, Japan and Canada. The flexibility and reliability of manipulator are greatly improved based on the advanced sense system and autonomous ability. For example, a refactoring gripper was designed by engineering college of Simon Fraster university of Canada in 1997. As shown in Figure 1, the gripper can grasp object with different shape by elastic deformation of touching. The greater adaptability and stability can be achieved but lower flexibility for this refactoring gripper.
Domestic research of robot started late, so the research of manipulator lags far relatively. From 1980s, the research of robot and manipulator have been developed well. The clapping gripper was designed by Shan Xi technology university, as shown in Figure 2. The clapping gripper can be achieved grasping the object with the screw-nut moving up and down while the screw rotating through the coupling by the drive motor. The working trace of the gripper is a curve.

3. Structure Designing of the Manipulator

3.1. Designing of the Mechanical Structure

The indicators and functions of the special robot are as follows, greater than 10kg load, grasping width 10cm above, space of gripper less than 5mm, less than 3kg weight, grasping and rotating.

According to the target and requirements, the system of manipulator consists of five major components: mechanical system, drive system, sensing system, control system and interactive system. As shown in Figure 3, the clamping device is consist of worm and worm-wheel. The motor can drive from worm rotating to two worm-wheels rotating in order to achieve clamping with the rotating axis of worm-wheel being perpendicular to the output shaft. The mechanical structure of the manipulator is designed by parallelogram lifting device making the clamping surface being parallel to each other. The gripper, as shown in Figure 4, which is called a pinch-type clamp, simulates a thumb and a finger. So the gripper have enough space to increase the diameter of the object it hold.

3.2. Designing of the Driving Module

The driving module consists of motor, driver, angle sensor, current sensor and reduction gears, as shown in Figure 5. The rotational movement of the gripper is achieved by the reduction gears through the motor 1. The manipulator can pick up and place object with the transmission mechanism by the motor 2. So different size objects can be pinched, hooked and cut by using extension tool.
The gripper is attached to the end of robotic arm, performing rotating and clamping. The force diagram of the gripper is shown in Figure 6. The manipulator can realize reliable and convenient connection between the robot end and the tool, and has the advantages of control mode, self-locking function and high safety.

As shown in Figure 6, suppose the 15kg load is horizontally carried by the gripper during working. The radial load is applied on the bearing (61806) when the gripper rotates. The 15kg load is 142mm distance from the bearing where 0 axial force is applied. So the radial load is,

\[
F_r = \frac{(15+1) \times 9.8 + 142}{10} = 2226.6 \text{ N}
\]

\[
F_a = mg = (15 + 1) \times 9.8 = 156.8 \text{ N}
\]

The bearing force is,

\[
F_c = (F_r^2 + F_a^2)^{1/2}
\]

In many cases, compared and analyzed, the axial force is applied on the bearing when grasping horizontally.

\[
F_a = F_r = 2226.6 \text{ N}
\]

The friction torque on the bearing is

\[
M_f = \frac{\mu F_d}{2} = \frac{0.0022 \times 2226.6 \times 30}{2} = 73.5 mNm
\]

The manipulator choose Maxon motor A-max22. The parameters of the motor as shown in Table 1.

| Parameter                      | Value       |
|-------------------------------|-------------|
| Rated Voltage (V)             | 12          |
| No-load Speed (rpm)           | 10200       |
| No-load Current (mA)          | 45.8        |
| Rated Speed (rpm)             | 7060        |
| Rated Torque (mNm)            | 6.96        |
| Interface Resistor (Ω)        | 5.53        |
| Interface Reactor (mH)        | 0.363       |
| Torque Constant (mNm/A)       | 10.9        |
| Rated Current (A)             | 0.681       |
| Locked Torque (mNm)           | 23.7        |
| Thermal Resistance (K/W)      | 20          |
| Winding Resistance (K/W)      | 6           |
| Environment Temperature (°C)  | -30~+85     |
| Winding Max Temperature (°C)  | +125        |
| Speed/Torque Slope (rpm/mNm)  | 444         |
The servo controller ESCON Module 50/8 is matched for the motor, the parameters of the driver is as shown in Table 2.

**Table 2. Parameters of ESCON Module 50/8**

| Parameter                          | Specification                                      |
|------------------------------------|----------------------------------------------------|
| Electric Specification             | +VCC 10 ~ 50 VDC                                   |
| Output Voltage(Max)                | 0.98 x +VCC                                       |
| Icont / Imax (<20 s)               | 8 A / 15 A                                        |
| PWM                                | 53.6 kHz                                           |
| Input and Output                   | A1 1 AI 2 12 Bit; −10 ~ +10 V ;                   |
|                                    | AO1 AO 2 12 Bit; −4 ~ +4 V ; GND                   |
|                                    | DI 1 DI 2 +2.4 ~ +36 VDC (Ri = 38.5 k Ω)           |
| Hall Sensor Power Voltage          | +5 VDC (IL ≤ 10 mA)                               |
| Encoder Power Voltage              | +5 VDC (IL ≤ 30 mA)                               |
| Motor Interface                    | DC Motor +motor, −motor                            |
|                                    | EC Motor winding 1, winding 2, winding 3            |
| Interface                          | USB 2.0 / USB 3.0 Full speed                       |
| Status Display                     | Run Green LED                                      |
|                                    | Error Red LED                                      |
| Environment Conditions             | Temperature(Run) −40 - +45 °C                      |
|                                    | Temperature(Storage) −40 - +85 °C                  |

The reduction ratio of transmission system of the manipulator is 8360 and the efficiency is 50%. So the output torque of the motor is,

\[ M_r = 6.96 \times 8360 \times 50\% = 29092.8 \text{ mNm} \quad (6) \]

Considering the gravity torque of the load, \( M_r \) is far more than \( M_f \) in order to meet the requirements. The general picture of the manipulator is shown in Figure 7.

![General picture of the manipulator](image)

**Figure 7.** General picture of the manipulator

### 4. The Structure Simulation of the Manipulator
The static analysis of the manipulator is performed by using the simulation tool of software Solidworks. According to the indicators and functions, the manipulator is fixed simulating the 15kg object hold. In order to enhance the pinch force, the grasping face is added with rubber pads to...
increase friction coefficient. The material of the grasping object is iron and the friction coefficient is 0.45. So the pinch force $F_Q$ is,

$$F_Q \mu = mg$$

(7)

$$F_Q = \frac{mg}{\mu} = \frac{15 \times 9.8}{0.45} = 294 N$$

(8)

The material properties for main components of the manipulator are shown in Table 3.

| Component       | Material    | Yield Strength (Mpa) | Elastic Modulus (GPa) | Mass Density (kg/m³) | Poisson’s Ratio |
|-----------------|-------------|----------------------|-----------------------|----------------------|-----------------|
| Joints          | 5052-O      | 90                   | 70                    | 2680                 | 0.33            |
| Turbine         | Brass       | 240                  | 100                   | 8500                 | 0.33            |
| Axis            | AISI304     | 207                  | 190                   | 8000                 | 0.29            |
| Rod             | 2014 Alloy  | 96.5                 | 73                    | 2800                 | 0.33            |
| Rod             | 6061 Alloy  | 275                  | 69                    | 2700                 | 0.33            |
| Support Rob     | 5052-O      | 72.4                 | 70                    | 2680                 | 0.33            |

As Table 3 shown, the yield strength of the rod material is improved optimizing from 2014 alloy to 6061 alloy but with same density. The stiffness and strength for the manipulator are both improved to get more safety and reliable when changing the material by simulation, as shown in Table 4.

| Stress (N/m²) | Before Optimized | After Optimized |
|--------------|------------------|-----------------|
| Minimum      | 2.726e+004       | 2.683e+004      |
| Maximum      | 1.049e+008       | 1.053e+008      |

| Displacement (mm) | Before Optimized | After Optimized |
|-------------------|------------------|-----------------|
| Minimum           | 0.000e+000       | 0.000e+000      |
| Maximum           | 4.761e-001       | 8.937e-001      |

5. Conclusion
The manipulator is compact and can grasp accurately using the parallelogram lifting device via control bus. The grasp force of the manipulator can be above 15Kg and the width of grasp is more than 10cm with the end space only 0mm. The manipulator meet the indicators and functions of specialized robot and can be used as a reference for other structure design of robot manipulator.
6. References

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