Design of a New Type of Hybrid Heavy Load Palletizing Robot

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Abstract. In the field of heavy-duty palletizing robot, the mature products in the market mostly adopt series mechanism, which has the disadvantages of long arm of each joint, large driving force and high cost. Although the robot with parallel mechanism does not have the above problems, its application is restricted due to its small working space. In this paper, a new type of hybrid mechanism has been designed. We analyzed the kinematic characteristics of the mechanism, used MATLAB to simulate the workspace and kinematics, and proved that it is suitable for heavy load palletizing.

1. Structural design

In the field of heavy load palletizing robot, series mechanism is still the mainstream, such as IRB 6650s robot [1] of ABB company and Kr Titan PA series [2] robot of KUKA company. However, their driving rods are subjected to both axial and radial forces. In order to resist the bending moment, it is necessary to use thicker bars and higher power motors. Most of the rods of the parallel mechanism only bear axial force. Among them, the two-dimensional translational parallel mechanism is one of the few degrees of freedom parallel mechanisms, which has the advantages of simple structure, strong bearing capacity, large working space, etc., and can be applied to palletizing robot [3].

Figure 1. Schema of the robot
1- drive module, 2- electric cylinder, 3- moving platform, 4- flange plate, 5- rotation shaft, 6-bracket, 7- slewing bearing, 8- base.
This paper adopted the scheme of hybrid mechanism, and Figure 1 is the three-dimensional diagram of hybrid palletizing robot. It is composed of 2(2-RPR) two-dimensional translational parallel mechanism and base. They are connected in series by a slewing bearing. A rotation shaft is installed on the moving platform, so that the object to be grabbed has a degree of freedom of rotation, so as to adjust the face direction of the object when being grabbed and stacking. The clamp is installed on the flange plate of the moving platform and connected with the rotating shaft. The movement of the moving platform is controlled by electric cylinders and slewing bearing. The working principle of the electric cylinders is shown in Figure 2 [4]. The two electric cylinders are placed in parallel, driven by the same servo motor, and telescoping synchronously. They are connected with the moving platform and bracket through the rotating pair. The electric cylinders are all two-force rods, bearing only axial force.

2. kinematic analysis

2.1 Forward kinematics analysis
Establish the D-H coordinate system of the mechanism as shown in Figure 3. Because the palletizing robot is a hybrid mechanism, the D-H parameters of the parallel part cannot be directly obtained [5], firstly, we have analysed the 2(2-RPR) parallel mechanism.
2.1.1 2(2-RPR) parallel mechanism

Set the midpoint of A3 and A4 wires as A5. It can be concluded that the position coordinates of A1, A2, and A5 in the coordinate system \{O1\} are \(A1 = (0, 0, a)^T\), \(A2 = (0, 0, -a)^T\), \(A5 = (0, 0, -2b)^T\). The position coordinates of B1 and B2 in the coordinate system \{O2\} are \(B1 = (0, 0, b)^T\), \(B2 = (0, 0, -b)^T\). Let \{O1\} be the fixed coordinate system and \{O2\} be the moving coordinate system of the parallel mechanism. Since there is no relative rotation between the moving platform and the bracket, the coordinate transformation matrix \(3R\) between the fixed coordinate system and the moving coordinate system is identity matrix. According to the theory of spatial coordinate transformation principle:

\[ L_i = \frac{1}{2}O + \frac{1}{2}RB_i - A_i \]

where \(L_i\) is the vector of each electric cylinder, \(\frac{1}{2}O = (x, y, z)\) is the coordinate of the origin of the moving coordinate system in the fixed coordinate system so the vector formulas of electric cylinders are:

\[ L_1 = L_2 = (x, 0, z - a + b) \]

\[ L_3 = L_4 = (x, 0, z + a + b) \]

According to formulas (1)-(2), inverse kinematics equations are:

\[ l_1 = l_2 = \sqrt{x^2 + (z - a - b)^2} \]

\[ l_3 = l_4 = \sqrt{x^2 + (z - a + b)^2} \]

Solving equations (3)-(4), X and Z are obtained, and the forward kinematics equations are obtained as follows:

\[ \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} l_2^2 - \frac{l_3^2 - 4(a-b)}{a+b} \\ 0 \\ \frac{l_3^2 - 4(a-b)}{a+b} \end{bmatrix} \]

2.1.2 hybrid mechanism

Based on the previous section, the D-H parameters table of palletizing robot is set up, as shown in Table 1.

| \(i\) | \(a_{i-1}\) | \(d_i\) | \(\theta_i\) |
|---|---|---|---|
| 1 | 0 | 0 | \(H\) | \(\theta_1\) |
| 2 | \(\sqrt{l_3^2 - \frac{l_2^2}{4(a-b)}}\) | \(0\) | \(\frac{l_2^2 - l_3^2}{4(a-b)}\) | 0 |
| 3 | \(d\) | 0 | -b | \(\theta_3\) |

Multiply the transformation matrixes of near two links to get the equation of motion:

\[ {^0}_T^3 = {^0}_T^1 {^1}_T^2 {^2}_T^3 T \]

\[ x_{O2} = \sqrt{l_2^2 - \frac{l_3^2 - 4(a-b)}{a+b}} \]

\[ z_{O2} = \frac{l_3^2 - 4(a-b)}{a+b} \]

Taking a point P on the flange as the research object, the homogeneous coordinate of P in the coordinate system \{O3\} is \([0 \ 0 \ 0 \ 1]^T\), and the coordinate of P in the fixed coordinate system \{O1\} is obtained by equation (6):

\[ \begin{bmatrix} P_x \\ P_y \\ P_z \\ 1 \end{bmatrix} = \begin{bmatrix} (r + x_{O2}) \cos \theta_1 \\ (r + x_{O2}) \sin \theta_1 \\ z_{O2} + H - b \end{bmatrix} \]
Set the rotation angle (around the Z₀ axis) is β, so

\[ \beta = \theta_1 + \theta_3 \]  

(8)

Formulas (7) - (8) are the forward kinematics equations of the hybrid heavy load palletizing robot.

2.2 Inverse kinematics analysis

Set \( c = a - b \), \( t = H - b \) according to formulas (7) and (8), the inverse kinematics equations of the hybrid heavy load palletizing robot can be obtained:

\[
\begin{align*}
 l_1 &= \sqrt{\left( \frac{P_x}{\cos \theta_3} - r \right)^2 + \left( P_z - t - c \right)^2} \\
 l_3 &= \sqrt{\left( \frac{P_x}{\cos \theta_3} - r \right)^2 + \left( P_z - t - c \right)^2 + 4c (P_z - t)} \\
 \theta_1 &= \tan^{-1} \frac{P_y}{P_x} \\
 \theta_3 &= \beta - \theta_1
\end{align*}
\]  

(9)

(10)

3. Simulation analysis

3.1 workspace simulation

According to the kinematics equation obtained in the previous chapter, we used MATLAB software to depict the working space of the robot by graphic method [6].

In this paper, the size and shape of the workspace are affected by the size of the mechanism, the length of the electric cylinder and the range of the rotation angle. The design parameters are: \( a = 500 \text{mm} \), \( b = 150 \text{mm} \), \( H = 2000 \text{mm} \), \( r = 200 \text{mm} \), the shortest length of the electric cylinder is \( l_{\text{min}} = 500 \text{mm} \), the longest length is \( l_{\text{max}} = 2500 \text{mm} \), the maximum outer diameter of electric cylinder is \( d = 90 \text{mm} \), and the rotation angle range of the slewing bearing is \(-180^\circ \sim 180^\circ\). In order to prevent interference, the rotating pair related to the electric cylinder has the maximum angle limit, as shown in Figure 4.

![Figure 4. Possible interference](image)

If the distance between the axis of two electric cylinders is \( D \), when \( d < D \), interference will occur. According to the knowledge of geometry, \( D = 2b \cdot \cos \alpha \). Therefore, the rotation angle must meet the requirements of \( \alpha > \cos^{-1} \frac{d}{2b} \). Put data into the inequality: \( \alpha < 72.54^\circ \), take \( \alpha = 70^\circ \). The simulation results are shown in Figure 5.
3.2 Kinematic simulation

In order to verify whether the working process is smooth, according to the forward kinematics solution, the movement law of each joint variable in the palletizing process is simulated. Taking the point P at the end of the moving platform as the research object, the displacement and velocity curves are obtained [7].

If the motion law of the two sets of electric cylinders be respectively \( l_1 = 500 + 200 \sin \left( \frac{\pi}{2} t \right) \), \( l_3 = 500 + 200 \cos \left( \frac{\pi}{2} t \right) \), and the relative motion relationship between the electric cylinder bracket and the base is \( \theta_1 = \frac{\pi}{6} t \).

The simulation results are shown in Figures 6 to 7. It can be seen that in the process of palletizing, the moving platform runs smoothly without sudden change of speed, which is very suitable for palletizing operation [8].

4. Conclusion

This paper synthesizes the advantages of series and parallel mechanisms, and designs a new type of hybrid heavy load palletizing robot with strong bearing capacity and large working space. This paper studies the kinematics analysis method of the hybrid mechanism, establishes the forward and inverse
kinematics equations of the robot, draws the curve of the working space and motion characteristic of the moving platform through MATLAB simulation, and proves that the design is suitable for the stacking situation.

Reference
[1] Shanghai ABB Engineering Co., Ltd. IRB robot product manual [Z]. Shanghai: Shanghai ABB Engineering Co., Ltd., 2008.
[2] KUKA robot (Shanghai) Co., Ltd. Kr robot series manual [Z]. Shanghai: KUKA robot (Shanghai) Co., Ltd.
[3] Li Kaiming, Zhang Yang, etc. A two-dimensional translational parallel mechanism with large workspace: China, 2018103242867 [P]. 2018.09.18.
[4] Zhou Dongzhen. Single drive two linkage redundant drive design and performance evaluation of parallel machine tool [D]. Nanjing University of technology, 2016.
[5] Liu Yang, Gao Zhihui, fan Chao, Li Yiwu. Kinematic analysis and Simulation of hybrid palletizing robot [J]. Mechatronics, 2010, (3): 57-60.
[6] Yuan huanlin, Luan Nan. Dynamic analysis and Simulation of hybrid stacking robot [J]. Mechatronics, 2013, (11): 74-76.
[7] Zou Xiaohui, Wang Hongzhou, Chen rUnLiu et al. Design and analysis of a new hybrid stacking robot [J]. Manufacturing automation, 2016, 38 (11): 91-94.
[8] Li Chengwei, Zhu Xiuli, fan Chao. Mechanism design and control system research of palletizing robot [J]. Mechatronics Engineering, 2008, 25 (12): 81-84.