Analysis and Simulation of Track Mobile Palletizing Robot Workplace in Koji Workshop

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Abstract

According to the working conditions of track palletizing robot in koji workshop, the robot workspace should be taken into consideration for motion analysis and trajectory planning. In this paper, the kinematics model is established by D-H method to analyze and solve the forward and inverse kinematics equations. Monte Carlo method is used to analyze the working space, and the robot's end point position aggregate has obtained via the solution of forward kinematics equation solved by MATLAB. The working space of the robot can be observed directly from the simulation results, which provides a reference for future work of space optimization and control system research.

Keywords

Palletizing Robot; Monte-Carlo Method; MATLAB; Workspace; Simulation.

1. Introduction

The size of the robot work space, is a set of points the robot actuator can reach under the restriction of its structure and normal work condition, represents the scope of activities of the robot, which is an important index of the robot's ability to work [1].

In order to meet the domestic liquor companies shelf koji production technology, a track mobile palletizing robot has been developed to achieve koji blocks' handling and stacking in fermentation workshop, see Fig.1. The robot must be able to meet the requirements of block handling and stacking in its work space. Robot Structure Design and Working Area.

2. An Overview of Shelf Koji-making Process in Workshop

The koji block size (mm) is about 300 × 200 × 100, liquor companies koji production process is: koji should be moved into fermentation room and then put onto the multi-layer shelves, after that the room must be sealed. Meanwhile, koji blocks are exchanged position on the shelves for better fermentation. After fermentation is complete, blocks are taken down the shelf and carried out. Currently domestic liquor companies koji needs for manual turning and handling koji in the koji room which leads to labor intensity. So the robot structure has been designed, its working scene model is shown in Fig. 1 and Fig. 2.

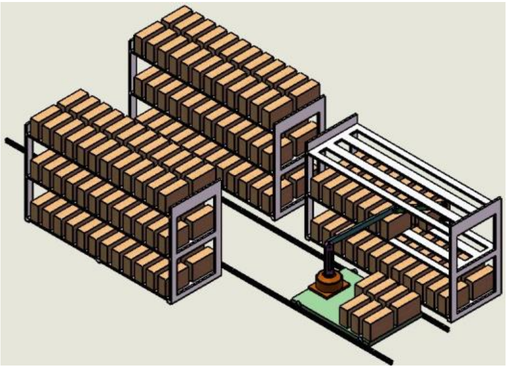


Fig. 1 Robot working scene

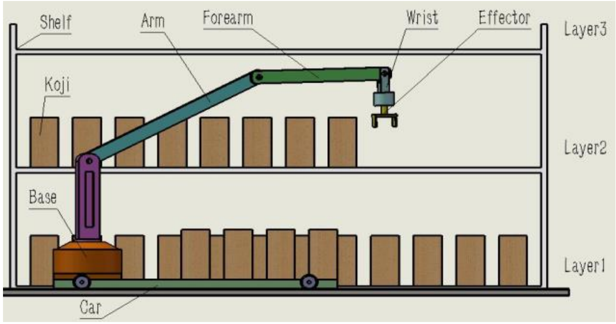


Fig. 2 Robot structure and working condition

2.1 Robot Structural Parameters

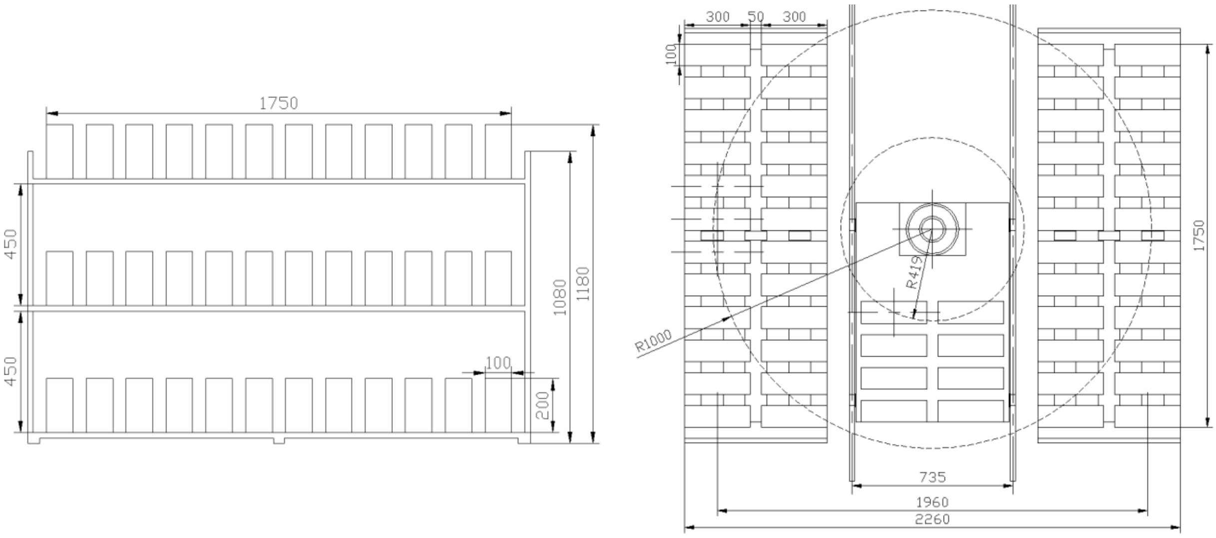
The structure of the robot includes a rail car robot, base, arm, forearm, wrist and end effector, its base fixed on the trolley guide rail for rotary motion [2]; between the arm and the forearm for pitch motion, as well as forearm and wrist, for rotary movement between the wrist and the end effector, the structure diagram as shown in Fig. 2.

According to their specific requirements, robot working radius of gyration R=1000mm, height from end execution to the shelf bottom H_0=1125mm; to meet working requirements, arm length L_1=700mm, forearm length L_2=450mm, wrist length L_3=130mm.

2.2 Robot Working Area in Workshop

After placement of koji blocks, as shown in Fig. 3 (a), from the top of the third layer block to the Shelf bottom is H0=1180mm, robot end effector can grab the block.

Robot should reach the working plane size as shown in Fig. 3 (b) , in which radius of rotation required within 1000mm for robot grasp outer blocks on the shelf, within 419mm for blocks on the small car near the rotary base.



(a) Height of the shelf

(b) Robot working plane

Fig. 3 Robot work area size

3. Establishment of Robot Kinematics Equation

3.1 Establishment of D-H Coordinate System

The robot's joints are all rotary joints, the establishment of coordinate system is shown in Fig. 4(in which Z2, Z3 and Z4 direction vertical to paper-based outwards), a2=700mm, a3=450mm, d4=130mm. The

DH parameters shown in table 1, where the range of rotation of the joint is determined by the structure and working conditions.

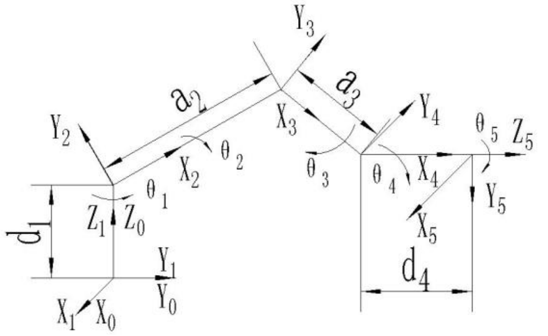


Fig. 4 Robot coordinate system

Table 1. Robot D-H Parameters

Link	θ_i /(°)	α_{i-1} /(°)	a_{i-1} /(mm)	d_i /(mm)	Joint Range /(°)
1	θ_1	0	0	d_1	-180~+180
2	θ_2	90	a_2	0	20~150
3	θ_3	0	a_3	0	-120~130
4	θ_4	0	0	d_4	35.5~50.5
5	θ_5	-90	0	0	-180~+180

3.2 Forward Kinematics Solution

The positive solution of the robot's kinematics is that the parameters of each joint of the robot are given, which are used to derive each link at any point pose [3~8]. When the equation of the forward kinematics of the robot has been established, the total transformation between the base and the end effector is the product of the four motion transformation matrix.

$$ {}^{i-1}_{\ \ i}\mathrm{T} = Rot(z_{i-1},\theta_i)Trans(z_{i-1},d_i)Trans(x_i,\alpha_i)Rot(x_i,\alpha_i) = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & -S\theta_i S\alpha_i & a_i C\theta_i \\ 0 & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ S\theta_i S\alpha_{i-1} & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

From (1) to know that the robot has five degrees of freedom, so there are five transformation matrix, the robot's forward kinematics equation is:

$$ {}^0_5\mathrm{T} = {}^0_1\mathrm{T}\,{}^1_2\mathrm{T}\,{}^2_3\mathrm{T}\,{}^3_4\mathrm{T}\,{}^4_5\mathrm{T} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

The parameters in table 1 are substituted into the formula (1), according to the forward kinematics equation (2), the 5-DOF robot end position and attitude can be obtained, concrete operation can be achieved by MATLAB. Among them:

$$n_x = C_1(C_{23}C_4C_5 - S_{23}S_4S_5) - S_1S_5$$
$$n_y = S_1(C_{23}C_4C_5 - S_{23}S_4S_5) + S_1S_5$$
$$n_z = S_{23}C_4C_5 + C_{23}S_4S_5$$
$$o_x = C_1(S_{23}S_4S_5 - C_{23}S_5C_4) - S_1C_5$$
$$o_y = S_1(S_{23}S_4S_5 - C_{23}S_5C_4) + C_1C_5$$
$$o_z = -S_{23}C_4S_5 - C_{23}S_5$$
$$a_x = C_1(-C_{23}S_4 - S_{23}C_4)$$
$$a_y = S_1(-C_{23}S_4 - S_{23}C_4)$$
$$a_z = C_{23}C_4 - S_{23}C_4$$
$$p_x = C_1[C_{23}(C2_4d_4 + a_3) - S_{23}d_4S2_4 + a_2C2_2]$$
$$p_y = S_1[C_{23}(C2_4d_4 + a_3) - S_{23}d_4S2_4 + a_2C2_2]$$
$$p_z = S_{23}(C2_4d_4 + a_3) + C_{23}d_4S2_4 + a_2S2_2 + d_1$$

3.3 Inverse kinematics solution

When the parameters of each joint have been determined, the robot will be able to reach the desired position. The position and orientation vectors are known when the robot's end coordinate system relative to the base coordinate system, in order to solve the various angles and distances, by inverse transform of ${}^{i-1}_{\ \ i}T^{-1}$ left multiplication the both sides of formula (2) and each joint variable can be obtained, the solve order is: θ_1, θ_5, θ_2, θ_3 and θ_4, shown as the following formula:

$$\theta_1 = \arctan(\frac{p_x}{p_y})$$
$$\theta_5 = \arcsin(C_1n_y - S_1n_x)$$
$$\theta_2 = \frac{1}{2}\arccos(\frac{C_1p_x + S_1p_y - d_4C_{234}}{a_2})$$
$$\theta_3 = \theta_{23} - \theta_2$$
$$\theta_4 = \frac{1}{2}\arcsin(\frac{p_z - d_1 - a_2S2_2}{d_4}) - \theta_{23}$$

After solving the inverse kinematics equation, there will be a number of solutions; the most suitable solution can be selected according to the parameters of the robot and its specific working environment.

4. Analysis and Simulation of Robot Working Space

4.1 Working space analysis of Monte Carlo method

The trajectory from the initial position to the end position of the robot in the working space is generated by ctraj and plot function in MATLAB Robotics Toolbox [4-11] , as shown in Fig. 5.

Currently, the main methods for solving the robot workspace including envelope method, analytical method, graphical method and numerical method. Among them, the envelope method is cumbersome to solve the boundary problem of the working space, and it is only applicable to the robot with the joint number less than 3; graphical method can be used to solve the working space boundary of the end effector of the robot and has good intuitive performance, but it is limited by the degree of freedom; analytic method can accurately express the analytic function of the working space boundary segment and solve problem quickly, but it is week in intuition, not ideal in general and practical application; numerical method is more universal, but encountered boundary surfaces are concave the truth will be reduced. With the continuous strengthening of the computer hardware, the solution of the robot working space prefers numerical method.

Combining MATLAB software, the working space is solved by numerical method. The key point of numerical method is how the computer can randomly select as many different combinations of joint variables as possible, here a random sample of numerical methods, the Monte Carlo method, can be used to realize the process.

The process of using Monte Carlo method to solve the robot working space is shown in Fig. 6.

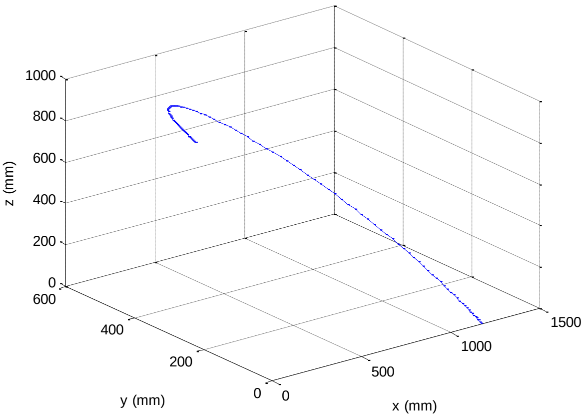


Fig. 5 Robot’s end trajectory

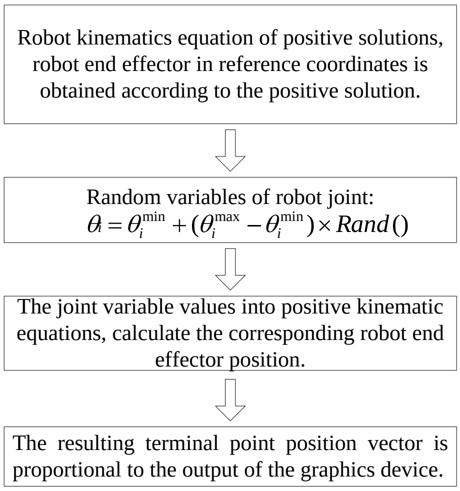


Fig. 6 Monte Carlo method for solving process

4.2 Research on space simulation

By the previous solution to get the coordinates of the robot end:

$$\begin{aligned} p_x &= C_1[C_{23}(C2_4 d_4 + a_3) - S_{23} d_4 S2_4 + a_2 C2_2] \\ p_y &= S_1[C_{23}(C2_4 d_4 + a_3) - S_{23} d_4 S2_4 + a_2 C2_2] \\ p_z &= S_{23}(C2_4 d_4 + a_3) + C_{23} d_4 S2_4 + a_2 S2_2 + d_1 \end{aligned} \tag{3}$$

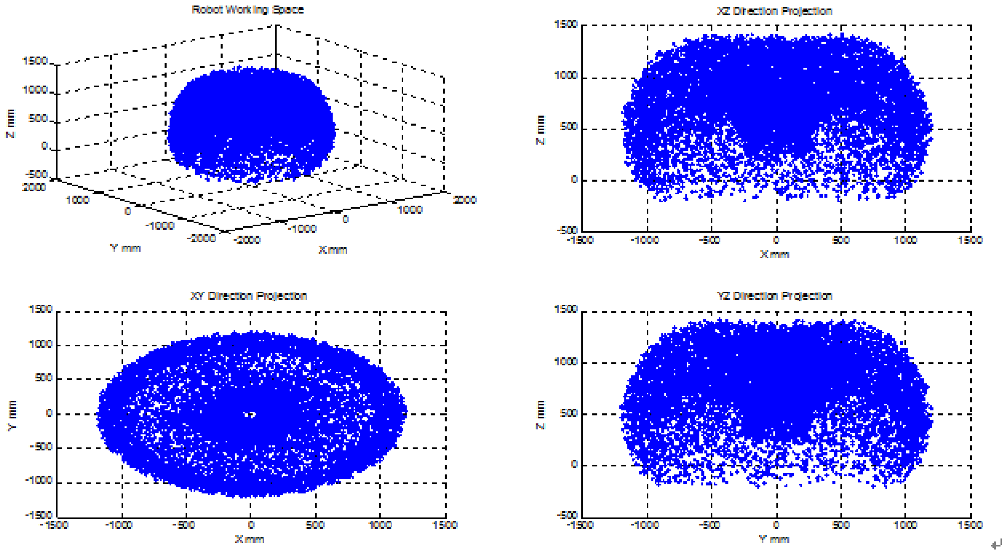


Fig. 7 Robot workspace point cloud

The robot end equations were written into a computer program by Monte Carlo method and MATLAB was used for simulation analysis, then the output of 20 000 points used to simulate a three-dimensional workspace of the robot, with a three-dimensional point cloud workspace and its YZ, XZ and XY plane on projection were obtained, shown in Fig.7:

Fig. 5 is the trajectory of the end effector on the side of the track the robot laying koji blocks, known from Fig. 7, when the robot laying koji blocks on both sides, the operating space formed into an approximately ellipsoid structure, the robot base is rotated in a circle, so the ellipsoid is closed.

5. Conclusion

The robot forward and inverse kinematic equation were established through D-H method, then its achievable working space was analyzed by the solution of the robot end effector position vector matrix, with the Monte Carlo method and MATLAB, the robot workspace has been simulated. Simulation results show that the working space of the robot is compact, which further illustrates that the Monte Carlo method has a positive effect for solving robot work space, provides an important basis for subsequent robotic space optimization and control system design.

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