Analysis on the Workspace of Six-degrees-of-freedom Industrial Robot Based on AutoCAD

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Abstract. This research discusses the workspace of the industrial robot with six degrees of freedom(6-DOF) based on AutoCAD platform. Based on the analysis of the overall configuration of the robot, this research establishes the kinematic mathematical model of the industrial robot by using DH parameters, and then solves the workspace of the robot consequently. In the AutoCAD, Auto Lisp language program is adopted to simulate the two-dimensional(2D) and three-dimensional(3D) space of the robot. Software user interface is written by using the dialog box control language of Visual LISP. At last, the research analyzes the trend of the shape and direction of the workspace when the length and angle range of the robot are changed. This research lays the foundation for the design, control and planning of industrial robots.

1 Introduction

At present, researches from China and abroad on the workspace of industrial robots have made some achievements [1-4]. The study of workspace of robot is inclined to use Monte Carlo method [5-7]. Hou Yulei [8] proposes a method for the workspace boundary extraction called ‘limit fixed interval angle’, based on the principles of bar limit combined with fixed joint variable. Tian Haibo [9] et al analyze manipulator's workspace by using Monte Carlo method and brings adaptive-divided mesh method to calculate the volume of workspace. Yi Jun [10]et al develop dynamic simulation system of robot based on AutoCAD. In this research, robot kinematics model by DH parameter method is improved, using Auto Lisp programming language to achieve six-degrees-of-freedom industrial robot workspace simulation. The influence of structure parameters on the shape and position of workspace and position is analyzed. This method also provides a powerful help for the design and research of industrial robot.

2 Description of 6-DOF industrial robot workspace

According to the modified DH parameter, the six-degree-of-freedom robot link coordinate system is established. See Figure 1.

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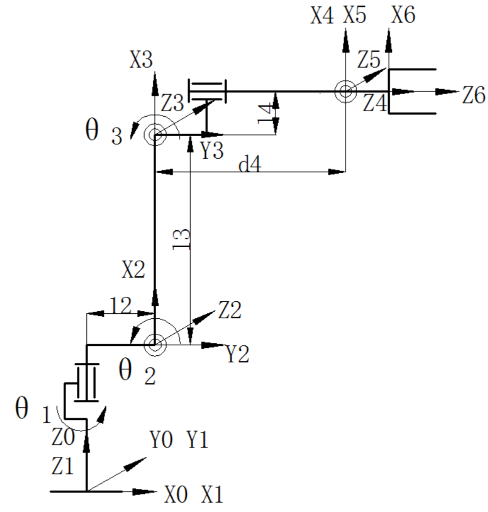

Figure 1. Schematic diagram of the robot.

The parameters of the robot D-H can be obtained as table 1:

Table 1. Robot DH parameter table.

i	a_{i-1} [m]	α_{i-1} [°]	d_i [mm]	θ_i [°]
1	0	0	0	θ_1
2	l_2	–90°	0	θ_2
3	l_3	0	0	θ_3
4	l_4	–90°	d_4	θ_4
5	0	90°	0	θ_5
6	0	–90°	d_6	θ_6

The position and attitude of the end of manipulator can be obtained through the robot coordinate system:

$$\boldsymbol{T} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

Where: $\begin{bmatrix} n_x & o_x & a_x \\ n_y & o_y & a_y \\ n_z & o_z & a_z \end{bmatrix}$ is the rotation matrix (attitude) of the robot end coordinate system with respect to base coordinate system; Formula (2) is the center of end position for robot. $c_i = \cos\theta_i$, $s_i = \sin\theta_i$, $c_{ij} = \cos(\theta_i + \theta_j)$, $s_{ij} = \sin(\theta_i + \theta_j)$.

$$\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} l_2 c_1 - d_4 c_1 s_{23} + l_4 c_1 c_{23} + d_4 s_1 + l_3 c_1 c_2 \\ l_2 s_1 - d_4 s_1 s_{23} - d_4 c_1 + l_4 s_1 c_{23} + l_3 c_2 s_1 \\ -l_4 s_{23} - d_4 c_{23} - l_3 s_2 \end{bmatrix} \tag{2}$$

3 Implementation of AutoCAD plug-in in the workspace of robot

Because of the simplicity of Visual LISP language syntax, the user can directly call the AutoCAD to draw through commends, and debug and check easily. Other languages will increase the complexity of development. Therefore, Visual LISP is used to calculate the software development.

In AutoCAD development environment with Visual Lisp, using Auto Lisp language file "*.lsp" is written to realize simulation of the robot workspace program. The user dialog interface file "*.dcl" format is generated, which is achieving the loading and display. Add a custom menu "Industrial Robot" to AutoCAD menu bar. Then load the "*.lsp" source code files and "*.dcl" dialog box file through the custom command macro. After the user clicks "OK" button, it gets the edit box and checks the input data. And then, it completes the follow-up program on the drawing commands of the workspace part at the time of closing the dialog box. Ultimately, two development of the software interface in AutoCAD is shown in Figure 2.

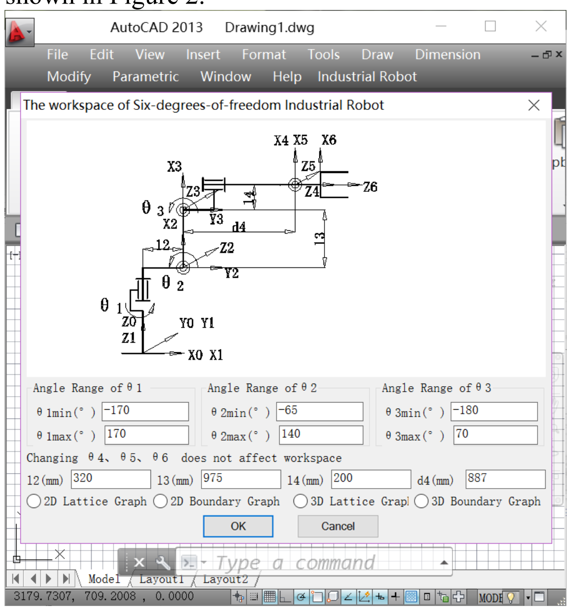

Figure 2. Robot workspace dialog box.

By the Formula (2), we can calculate the 2D workspace of the robot in which end reference point is formed on the base coordinate system. Combined with the scope of the angle and the initial value of length parameters, the section of workspace in the YOZ direction can be gotten when $\theta_1=90°$. See the use of Auto LISP programming in Figure 3. On the basis of 2D workspace, changing θ_1 from the minimum value gradually increased to the maximum value, the 3D workspace of the robot with six degrees of freedom can be obtained.

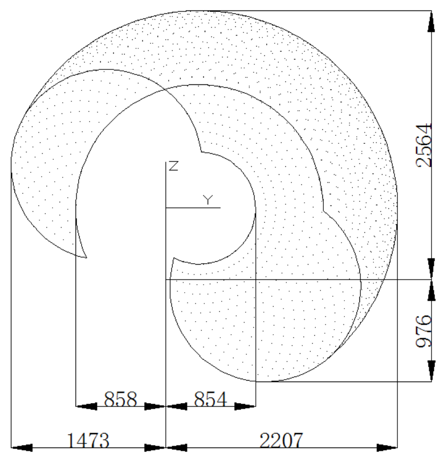

Figure 3. 2D space diagram with the solid boundary range.

4 The influence of structural parameters on the workspace of the robot

The workspace of the robot is drawn by the software written by LISP Visual to understand the influence of the change of the structure parameters on the workspace. The main variables are the length variable l_2、l_3、d_4 , and angle variable θ_2 、θ_3. Because of the small impact of l_4, it is not considered. The original image and the picture after changing the mechanism parameters will be put together for the convenience of comparison

4.1 The influence of the changing rod length on workspace

The boundary map of the workspace is obtained by setting value of l_2 in turn as shown in Figure 4. Analysis shows that, when other parameters are kept constant, only increasing or decreasing the l_2 , the size and shape of the YOZ working plane remain unchanged, that is to say only changing the position of the workspace. When the increase l_2 , the YOZ working plane has a tendency to move upward; otherwise, it is downward.

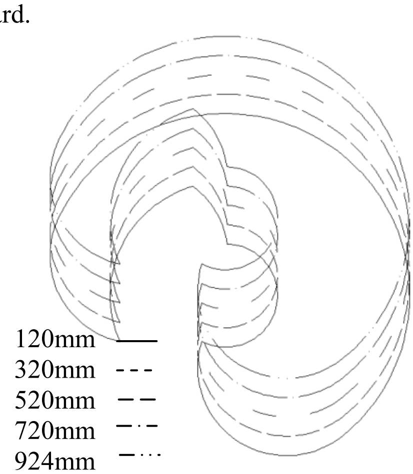

Figure 4. YOZ plane change trend chart when changing l_2 .

Figure 5 is the boundary map of the workspace when l_3 is changed. The analysis shows that when other parameters remain unchanged and increase l_3, the YOZ working plane has a tendency to move upward, meanwhile, the area increases; otherwise the opposite. Figure 6 is the boundary map when d_4 is changed. We can know that when other parameters remain unchanged, only increase the d_4, the robot YOZ working plane area increased, otherwise decreased.

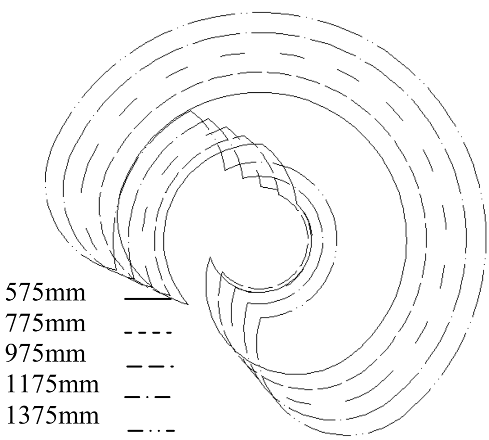

Figure 5. YOZ plane change trend chart when changing l_3

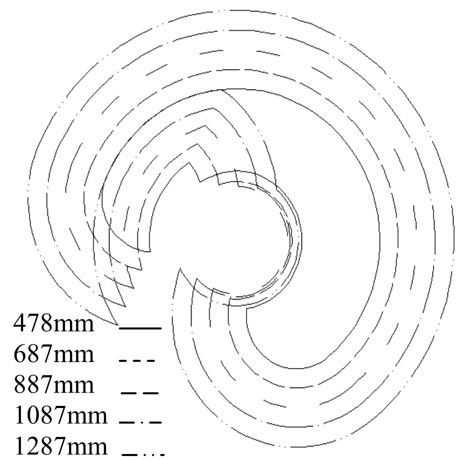

Figure 6. YOZ plane change trend chart when changing d_4

4.2 The Influence of the Changing Angle Range on the Workspace

As shown in Figure 7, the boundary map of workspace is obtained after the change of scope of θ_2. Analysis shows that when other parameters are kept constant and only the angel range of θ_2 is increased, the YOZ working plane of the robot is expanded gradually and the area increases, otherwise it will decrease.

Figure 8 is obtained from changing of θ_3. Analysis shows that, when other parameters remain unchanged, the YOZ working plane area of the robot is increased with the increase of the angle; otherwise it will decrease. And when the angle range increases to a certain degree, the YOZ working plane interior will change from the depression into the bulge. This situation should be paid attention to when designing.

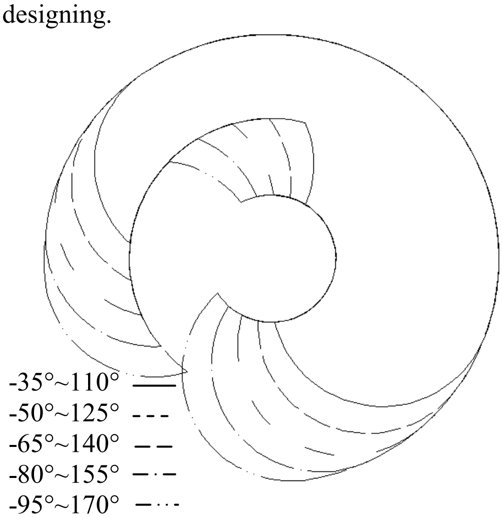

Figure 7. YOZ plane change trend chart when changing θ_2.

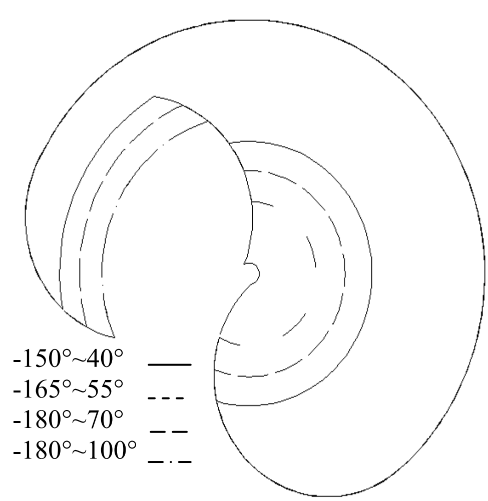

Figure 8. YOZ plane change trend chart when changing θ_3.

5 Conclusion

Through secondary development on AutoCAD platform, the workspace of six degrees of freedom industrial robot is studied. According to the modified DH parameter, the modeling of the robot is carried out. Using Visual LISP the dialog interface program is written to simulate the workspace of the robot. By changing the input parameters, the workspace can be quickly and accurately drawn and the range of motion of the robot can be calculated. So the influence of structural parameters on the workspace can be analyzed directly. This is a clear, simple and effective method to determine the workspace of industrial robot. The method can quickly determine the structure size and the range of motion of the robot according to the design requirements of the work, so as to improve the working efficiency. At the same time, it also creates a good basic condition for the robot dynamics analysis, trajectory planning and motion control.

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