# Kinematic Model Analysis of an 8-DOF Photographic Robot 

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#### Abstract

The photographic robot studied in this chapter is an 8-DOF PRRPR-S type. In order to obtain a stable and repeatable lens shooting trajectory, it is necessary to balance the robot's own weight and structural rigidity. First, based on the structural analysis of the photographic robot, the main parameters of the mechanism design are extracted. Then, with the help of the photographic robot calibration, the kinematics model of the robot is established. The DH model is applied on the first seven axes of the photographic robot. The 6-parameter model is used on the end actuator attitude adjustment rotation axis. Finally, the motion of each axis is simulated in MATLAB, which verifies the kinematic model.


Keywords Photographic robot - Kinematics analysis • DH model 6-parameter model

## 1 Introduction

The photographic robot can accurately reproduce the graphics and export the shooting trach at the same time, which cannot be realized by the manual operation. It is an important tool, used for shooting source material, for digital image synthesis technology, which provides the foundation for the creation of visual effects. At present, the use of photographic robots requires professional operators to participate. This approach has been approved to be time-consuming, which is less efficient. The purpose of this chapter is to establish the kinematic model of the 8-DOF photographic robot. This allows the operator to specify the target position of the end actuator and simplify the operation mode. The photographic robot controls the

[^0]movement of cameras and can monitor the welding process at a specified location in real time. This will make photographic robots widely used in welding manufacturing. While modeling is the key process of robot kinematics analysis, the DH modeling method is one of the most commonly used modeling methods [1, 2]. In this chapter, the first seven axes of the photographic robot are developed by this modeling method. However, this model acts singularly when the adjacent two joint axes of the robot are parallel or nearly parallel. Therefore, when parallel axes occur, the rotation of one $y$ axis will be increased to avoid the singularity problem [3]. The rotation axis, which is performed by the actuator at the end for attitude adjustment, uses a 6-parameter S-model [4]. According to the kinematic model established by this method, the pose matrix of the end actuator can be obtained more accurately, which in practice has a great application value.

## 2 Schematics and Zero Status Parameter Tables

In this chapter, the type of photography robot is an 8-DOF PRRPR-S type, with complete spatial positioning capability. It belongs to the double redundant freedom robot. Physical prototype and key components are named as in Fig. 1. Compared with the traditional industrial robots, the arm can be elongated, and the robot body structure can be moved in a linear orbit. The kinematics model of the robot is established depending on each link as a rigid body. Kinematics model research mainly solves the problem of robot positioning, especially for describing the positional relationship between one connecting rod and another.

In this chapter, the DH method is used to model the photographic robot, while the 6-parameter model method is used for the end actuator transformation matrix. The above statement has already taken the calibration requirements into account. DH modeling methods in different literature are slightly different. The coordinate system $\{i\}$ in this chapter is attached to the connecting rod $i$ at the origin of the joint axis of the connecting rod. The specification of the additional coordinate system of the connecting rod is summarized as follows:
(1) For the coordinate system $\{i\}$ of the connecting rod $i$, the $Z$ axis is pointing in the axial direction of the joint axis, and for the linear motion axis, the axial direction is the direction of the motion axis;
(2) The $X$ axis of the coordinate system $\{i\}$ is the vertical direction of the coordinate system $\{i-1\} Z$ axis and the coordinate system $\{i\} Z$ axis. The $Y$ axis of the coordinate system $\{i\}$ is determined by the right-hand rule according to the $X$ axis and $Z$ axis.


Fig. 1 Photographic robot movement axes and key parts named

Thus, the establishment of the photographic robot connecting rod coordinate system is shown in Fig. 2.

There are eight motion axes in the photographic robot, respectively, the bottom linear motion axis $r_{1}$, the bottom ring rotation axis $\theta_{2}$, the top of the ring structure rotation axis $\theta_{3}$, the top linear motion axis $r_{4}$, the top line structure distal pitch rotation axis $\theta_{5}$, the end actuator attitude adjustment rotation axis $\theta_{6}$, pitch axis $\theta_{7}$ and roll axis $\theta_{\mathrm{ee}}$. Considering the zero state of the photographic robot, based on the DH and 6-parameter models, the kinematic link parameters of the photographic robot are obtained, as shown in Table 1. When the photographic robot is located in the zero state, the movement amount of each motor shaft is 0 . The position and attitude of the photographic robot are shown in Table 1.


Fig. 2 Connecting rod coordinate system

Table 1 Photographic robot kinematic link parameters table

| Parameter |  |  |  |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Vary | Type | $i$ | 1 | 2 | 3 | 4 | 5 | 6 |
| W-0 | 1 | 0 | $\pi / 2$ | 0 | 0 | $\pi / 2$ | - | - |
| $0-1$ | 1 | 1 | 0 | $r_{1}+r_{10}$ | 0 | $-\pi / 2$ | - | - |
| $1-2$ | 1 | 2 | $-\pi / 2$ | $r_{2}$ | 0 | $-\pi / 2$ | - | - |
| $2-3$ | 1 | 3 | $-\pi / 2$ | 0 | $l_{3}$ | $-\pi / 2$ | - | - |
| $3-4$ | 1 | 4 | 0 | $r_{4}+r_{40}$ | 0 | $\pi / 2$ | - | - |
| $4-5$ | 1 | 5 | $\pi / 2$ | 0 | 0 | $-\pi / 2$ | - | - |
| $5-6$ | 1 | 6 | 0 | $r_{6}$ | 0 | $\pi / 2$ | - | - |
| $6-7$ | 1 | 7 | $-\pi / 2$ | 0 | 0 | $-\pi / 2$ | - | - |
| $7-\mathrm{EE}$ | 2 | EE | 0 | 0 | 0 | 0 | 0 | 0 |

## 3 Transformation Matrix

### 3.1 Transformation Matrix Type 1-DH ( $\boldsymbol{\theta}$ r l $\alpha$ )

The DH transformation matrix means that in the coordinate system $\{i\}$, it rotates $\theta$ around the current $Z$ axis, then moves $r$ along the $Z$ axis, next moves $l$ along the $X$ axis, afterward rotates $a$ around the $X$ axis. The formula of the transformation matrix of DH modeling is

$$
\mathbf{A}_{\mathrm{DH}}=\left[\begin{array}{cccc}
\cos \theta & -\cos \alpha \cdot \sin \theta & \sin \theta \cdot \sin \alpha & l \cdot \cos \theta  \tag{1}\\
\sin \theta & \cos \alpha \cdot \sin \theta & -\cos \theta \cdot \sin \alpha & l \cdot \sin \theta \\
0 & \sin \alpha & \cos \alpha & r \\
0 & 0 & 0 & 1
\end{array}\right]
$$

### 3.2 Transformation Matrix Type 2-EE (6-Parameter Transformation Matrix)

The 6-parameter transformation matrix means that, in the coordinate system $\{i\}$, the following transformation is performed in the new coordinate system after the transformation, it rotates $\theta$ around the $Z$ axis, rotates $\beta$ around the $Y$ axis, rotates $\alpha$ around the $X$ axis, then moves $x$ along the $X$ axis, moves $y$ along the $Y$ axis and finally moves $z$ along the $Z$ axis. The EE modeling transformation matrix formula is

$$
\left.\begin{array}{c}
\mathbf{A}_{\mathrm{ee}}=\left[\begin{array}{ccc}
\cos \beta \cdot \cos \theta & \cos \theta \cdot \sin \alpha \cdot \sin \beta-\cos \alpha \cdot \sin \theta & \sin \alpha \cdot \sin \theta+\cos \alpha \cdot \sin \beta \cdot \cos \theta \\
\cos \beta \cdot \sin \theta & \sin \theta \cdot \sin \alpha \cdot \sin \beta+\cos \alpha \cdot \cos \theta & -\sin \alpha \cdot \cos \theta+\cos \alpha \cdot \sin \beta \cdot \sin \theta \\
-\sin \beta & \cos \beta \cdot \sin \alpha & \cos \alpha \cdot \cos \beta \\
0 & 0 & 0
\end{array}\right] \\
z \cdot(\sin \alpha \cdot \sin \theta+\cos \alpha \cdot \sin \beta \cdot \cos \theta)-y \cdot(\cos \alpha \cdot \sin \theta-\cos \theta \cdot \sin \alpha \cdot \sin \beta)+x \cdot \cos \beta \cdot \cos \theta \\
-z \cdot(\sin \alpha \cdot \cos \theta-\cos \alpha \cdot \sin \beta \cdot \sin \theta)+y \cdot(\cos \alpha \cdot \cos \theta+\sin \theta \cdot \sin \alpha \cdot \sin \beta)+x \cdot \cos \beta \cdot \sin \theta \\
z \cdot \cos \alpha \cdot \cos \beta-x \cdot \sin \beta+y \cdot \cos \beta \cdot \sin \alpha \\
1 \tag{2}
\end{array}\right]
$$

From the above analysis, the photographic robot transformation matrix is obtained

$$
\begin{gather*}
\mathbf{A}_{0}=\left[\begin{array}{cccc}
0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{3}\\
\mathbf{A}_{1}=\left[\begin{array}{cccc}
1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & -1 & 0 & r_{1}+r_{10} \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{4}\\
\mathbf{A}_{2}=\left[\begin{array}{cccc}
\cos \left(\theta_{2}-\pi / 2\right) & 0 & -\sin \left(\theta_{2}-\pi / 2\right) & 0 \\
\sin \left(\theta_{2}-\pi / 2\right) & 0 & \cos \left(\theta_{2}-\pi / 2\right) & 0 \\
0 & -1 & 0 & r_{2} \\
0 & 0 & 0 & 1
\end{array}\right] \tag{5}
\end{gather*}
$$

$$
\begin{align*}
& \mathbf{A}_{3}=\left[\begin{array}{cccc}
\cos \left(\theta_{3}-\pi / 2\right) & 0 & -\sin \left(\theta_{3}-\pi / 2\right) & l_{3} \cdot \cos \left(\theta_{3}-\pi / 2\right) \\
\sin \left(\theta_{3}-\pi / 2\right) & 0 & \cos \left(\theta_{3}-\pi / 2\right) & l_{3} \cdot \sin \left(\theta_{3}-\pi / 2\right) \\
0 & -1 & 0 & 0 \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{6}\\
& \mathbf{A}_{4}=\left[\begin{array}{cccc}
1 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 \\
0 & 1 & 0 & r_{4}+r_{40} \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{7}\\
& \mathbf{A}_{5}=\left[\begin{array}{cccc}
\cos \left(\theta_{5}+\pi / 2\right) & 0 & -\sin \left(\theta_{5}+\pi / 2\right) & 0 \\
\sin \left(\theta_{5}+\pi / 2\right) & 0 & \cos \left(\theta_{5}+\pi / 2\right) & 0 \\
0 & -1 & 0 & 0 \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{8}\\
& \mathbf{A}_{6}=\left[\begin{array}{cccc}
\cos \theta_{6} & 0 & \sin \theta_{6} & 0 \\
\sin \theta_{6} & 0 & -\cos \theta_{6} & 0 \\
0 & 1 & 0 & r_{6} \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{9}\\
& \mathbf{A}_{7}=\left[\begin{array}{cccc}
\cos \left(\theta_{7}-\pi / 2\right) & 0 & -\sin \left(\theta_{7}-\pi / 2\right) & 0 \\
\sin \left(\theta_{7}-\pi / 2\right) & 0 & \cos \left(\theta_{7}-\pi / 2\right) & 0 \\
0 & -1 & 0 & 0 \\
0 & 0 & 0 & 1
\end{array}\right]  \tag{10}\\
& \mathbf{A}_{\mathrm{ee}}=\left[\begin{array}{cccc}
\cos \theta_{\mathrm{ee}} & \sin \theta_{\mathrm{ee}} & 0 & 0 \\
-\sin \theta_{\mathrm{ee}} & \cos \theta_{\mathrm{ee}} & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{array}\right] \tag{11}
\end{align*}
$$

The position of the end actuator coordinate system in the world coordinate system is

$$
\begin{equation*}
T_{\mathrm{ee}}=\mathbf{A}_{1} \cdot \mathbf{A}_{2} \cdot \mathbf{A}_{3} \cdot \mathbf{A}_{4} \cdot \mathbf{A}_{5} \cdot \mathbf{A}_{6} \cdot \mathbf{A}_{7} \cdot \mathbf{A}_{\mathrm{ee}} \tag{12}
\end{equation*}
$$

Among them, $r_{1}=0, r_{4}=0, r_{10}=1000, r_{2}=300, l_{3}=333, r_{40}=333, r_{6}=963, r_{1}=0$.
In Fig. 2, $r_{20}=$ 1969. $r_{20}$ is the distance from the upper surface of the bottom linear track to the top of the ring structure rotation axis. It is assumed that the height of the upper surface of the bottom linear track is used as the origin height of the world coordinate system. However, under the consideration that the positional expression of the photographic robot contains interrelated link parameters, the world coordinate system is placed in the middle of the two tracks, which makes the height lower than the height of the ring structure's top.


Fig. 3 Rotating platform model: a bottom linear motion axis; $\mathbf{b}$ top of the ring structure rotation axis; $\mathbf{c}$ bottom ring rotation axis; $\mathbf{d}$ top linear motion axis; $\mathbf{e}$ top line structure distal pitch rotation axis; $\mathbf{f}$ end actuator attitude adjustment rotation axis; $\mathbf{g}$ end actuator attitude adjustment pitch axis; $\mathbf{h}$ end actuator attitude adjustment pitch roll axis

## 4 Verification of Kinematics Model

In this chapter, the kinematics model of the photographic robot is displayed graphically with MATLAB software. It moves as much as possible within the motion range of each joint of the photographic robot [5]. As shown in Fig. 3, the green dotted line is the initial zero position of the photographic robot, the blue solid line is the end state of the motion of the photographic robot, the sky and black is the posture of the end actuator, and the red dotted line is the end actuator motion trajectory of the photographic robot. Among them, some photographers at the end of the kinetic model of movement state and the initial zero state coincidence, resulting in green dotted line is blocked by a blue solid line.

The figure shows the initial zero state, the motion end state and the end actuator motion trajectory of each axis of an 8-DOF robot. It can be seen from the figure that the end actuator of the photographic robot moves continuously from the initial zero position of the photographic robot to the end state of the motion of the photographic robot along the trajectory, and it is possible to visually see the eight axes of the photographic robot during the simulation animation passes through the continuous points of the trajectory, which fully complies with the requirements of the photographic robot design.

## 5 Conclusion

According to the calibration requirements of the 8 -DOF photographic robot, both the DH model and the 6-parameter model has been purposed to establish the coordinate system and model. Through MATLAB simulation, it is shown that the kinematics simulation of the photographic robot can be realized by MATLAB software, which proves that the photographic robot can accurately move along with the desired trajectory on the computer. Overall, the discussed method has been proved to be complete, continuous and practical.

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