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Analysis and Simulation of a 6R Robot in Virtual Reality

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Abstract: To analyse the motion of a 6R robot, the inverse kinematics analysis was performed. Virtual reality makes it visible and verisimilar to simulate the robot motion as well as to verify the inverse kinematics analysis and the consistency of pose for the robot. In virtual reality, which is developed by EON Studio software, the robot motion is realized by joints control which requires the joint control functions instead of the use of teach pendant in practice. Addressing the particular difficulties, the MATLAB software was used for performing inverse kinematics analysis as well as to fit the control functions of the joints. The combination of MATLAB and EON can realize the control of a 6R robot to validate smooth motions in virtual reality.

Keywords: inverse kinematics, 6R robot, virtual reality, MATLAB, EON

1. INTRODUCTION

6R robots are indispensable in agriculture. They are widely used in plant factory as well as machinery manufacturing. To improve the agricultural machinery manufacturing, the 6R welding robot plays a very important role. Bolmsjo, G, et al (2002) have indicated that so many scholars have studied the control methods of the welding robot.

Since the end-effector is the working part, inverse kinematics analysis is the key to control the robot. The inverse kinematics solutions of the 6R robot can be classified into two broad categories: closed-form solutions and numerical solutions. The determination of analytical solutions is necessarily burdened with multi-parameters, nonlinearity, and coupling of the solutions (Liu and Huang, 2012). When expressed mathematically, the objective is to solve a series of multivariate equations (Manocha and Canny, 1994), thus prompting the prolonged effort in seeking to simplify or streamline analytical methods. Qiao et al, (2010) presented a double quaternion based kinematics formulation for the general 6R robots to simplify the solution procedures. By considering the various properties of the exponential rotation matrices, Özgören (2002) applied topology analysis to simplify the kinematic equations and obtained both the analytical and semi-analytical solutions for their manipulator.

MATLAB Robotic Toolbox is also widely employed for inverse kinematics analysis (Swaraj and Sharad, 2014). It was convenient to obtain the inverse kinematics solutions by inputting the D-H parameters and the transformation matrices. It was also used in the motion simulation of the 6R robot. However, it does not provide the true motion of the robot model it simulates as it disregards the very fact that the robot is established by links with specific configurations. To simulate robot motions, virtual reality with EON studio software is preferred.

Virtual reality makes it visible and verisimilar to simulate the robot motion as well as to verify the inverse kinematics analysis and the consistency of pose for the robot (Raúl et al, 2015). The study started very early , Peter Sorenti et al, (1997) introduced a 3D robotics simulation software called GRASP-VRI, which has been created specifically for the shipbuilding industry to make the preparation of programs for robotic arc-welding a rapid and effective process. Now, there are great varieties of softwares for virtual reality and EON Studio software is selected in this paper. EON Studio is a development tool to produce the VR application, developed by EON Reality, Inc. Using EON Studio properly, developers can quickly and easily create the VR application (Wang, 2010) . Since the robot motion in EON Studio is realized by joints control which requires the joint control functions instead of the use of teach pendant in practice, a method of fitting functions in MATLAB is presented in this paper.

2. ROBOT KINEMATICS MODEL

Fig. 1 showed the three-dimensional configuration of a 6R arc welding robot with a coordinate frame defined for each link. Each frame was named by the number of the link to which it is attached.

The robot was used to weld the frame of 4LZK-2.0 wheat harvester.

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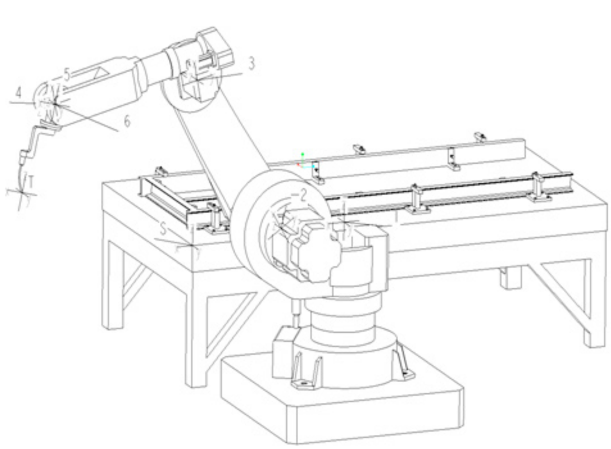

Fig. 1. Six-axis arc welding robot with link and frame assignments

The corresponding Denavit-Hartenberg (D-H) parameters tabulated in Table 1 were defined according to the robot structure and the position of the frames.

Table 1. Denavit-Hartenberg parameters

i	α_{i-1} /(°)	a_{i-1} /(mm)	d_i /(mm)	θ_i /(rad)
1	0	0	0	(-3.142,3.142)
2	90	425.42	0	(-1.22,3.142)
3	0	1000	118	(-1.22,4.00)
4	90	145.17	953	(-3.142,3.142)
5	-90	0	0	(-2.53,2.53)
6	-90	0	0	(-6.284,6.284)

The coordinate transformation matrix ${}^{i-1}_{i}T$, expressed in (1), defined frame {i} relative to frame {i-1} with "$s\theta_i$" being the abbreviation for "$\sin\theta_i$" and "$c\theta_i$" for "$\cos\theta_i$".

$$ {}^{i-1}_{i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

$$ {}^{0}_{1}T = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

The transformation that relates frame {6} to frame {0} can be obtained by multiplying the following link transformation matrices, as shown in (3).

$$ {}^{0}_{6}T = {}^{0}_{1}T \bullet {}^{1}_{2}T \bullet {}^{2}_{3}T \bullet {}^{3}_{4}T \bullet {}^{4}_{5}T \bullet {}^{5}_{6}T \quad (3) $$

$$ {}^{0}_{6}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

Once the position of every joint is available, the Cartesian position and orientation of the last link can be calculated using (3). The matrix ${}^{0}_{6}T$ in (4) has the expressions of all the joint variables as its entries.

3. INVERSE KINEMATICS

To calculate θ_i from ${}^{0}_{6}T$, each side of (3) is left-multiplied by $\left({}^{0}_{1}T\right)^{-1}$, followed by replacing ${}^{1}_{6}T$ with ${}^{1}_{3}T \bullet {}^{3}_{6}T$ as follows:

$$ ({}^{0}_{1}T)^{-1} \bullet {}^{0}_{6}T = {}^{1}_{3}T \bullet {}^{3}_{6}T \quad (5) $$

Equating the (2, 4) elements on both sides of (5), one has:

$$ -s\theta_1 p_x + c\theta_1 p_y = -d_3 \quad (6) $$

After a few manipulations it can be shown that θ_1 is of the form below:

$$ \theta_1 = \operatorname{atan} 2(p_y, p_x) - \operatorname{atan} 2(-d_3, \pm\sqrt{p_x^{\,2} + p_y^{\,2} - d_3^{\,2}}) \quad (7) $$

Recast (3) by left-multiplying both sides by $({}^{1}_{2}T)^{-1} \bullet ({}^{0}_{1}T)^{-1}$ result in the followings:

$$ ({}^{1}_{2}T)^{-1} \bullet ({}^{0}_{1}T)^{-1} \bullet {}^{0}_{6}T = {}^{2}_{3}T \bullet {}^{3}_{6}T \quad (8) $$

$$ \begin{bmatrix} c_1 c_2 & c_2 s_1 & s_2 & -a_1 c_2 \\ -s_2 c_1 & -s_1 s_2 & c_2 & a_1 s_2 \\ s_1 & -c_1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ = \begin{bmatrix} c_3 & -s_3 & 0 & a_2 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \bullet \quad (9) $$

$$ \begin{bmatrix} c_4 c_5 c_6 + s_4 s_6 & c_6 s_4 - c_4 c_5 s_6 & -c_4 s_5 & a_3 \\ c_6 s_5 & -s_5 s_6 & c_5 & -d_4 \\ -c_4 s_6 + c_5 c_6 s_4 & -c_4 c_6 - c_5 s_4 s_6 & -s_4 s_5 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

To be brief here, "s_i" is the abbreviation for "$\sin\theta_i$" and "c_i" for "$\cos\theta_i$". Equating the (1, 4) elements and the (2, 4) elements on both sides of (9), respectively, one obtains two equations involving θ_1 , θ_2 , and θ_3 as shown in (10).

$$ c\theta_1 c\theta_2 p_x + c\theta_2 s\theta_1 p_y + s\theta_2 p_z - a_1 c\theta_2 - a_2 = a_3 c\theta_3 + d_4 s\theta_3 \quad (10) $$

$$ -c\theta_1 s\theta_2 p_x - s\theta_1 s\theta_2 p_y + c\theta_2 p_z + a_1 s\theta_2 = a_3 s\theta_3 - d_4 c\theta_3 \quad (11) $$

To eliminate θ_3 , the two equations are squared first and then followed by adding the resulting equations,

$$ \theta_2 = \operatorname{atan} 2(k_2 / \rho_2, \pm\sqrt{1 - k_2^{\,2} / \rho_2^{\,2}}) - \operatorname{atan} 2(B_2, A_2) \quad (12) $$

where