Research on Inverse Kinematics Algorithm of 6-DOF Industrial Robot Based on RBF-PID

Dongkang He¹, Fusheng Shi²*, Shunxue Tan¹ and Qigui Deng¹

¹School of Mechanical and Electrical, Liuzhou Vocational &Technical College, Liuzhou, China
²School of Automotive Engineering, Liuzhou Vocational &Technical College, Liuzhou, China

*Corresponding author email: 234260580@qq.com

Abstract. To solve the question of multi value and precision in the process of designing the inverse kinematics controller of 6-DOF Industrial robot, a radial basis function-proportional integral differentiation(RBF-PID) adaptive controller method has been proposed to train the inverse kinematics model of industrial robot. Compared with the traditional RBF neural network, the advantage of RBF-PID adaptive controller was that it had high search efficiency and was not easy to fall into local optimal solution. The simulation results showed that this method could not only overcome the influence of the initial value selection of the traditional RBF neural network learning algorithm on the network performance, but also had a good solution accuracy for the inverse kinematics of the 6-DOF Industrial robot. Compared with the traditional RBF neural network algorithm, the RBF-PID adaptive controller method had improved the performance of overshoot, adjustment time and anti-interference, and solved the problem of solving the multivalued inverse kinematics algorithm.

1. Introduction
Robot kinematics describes the motion relationship between robot joints and the rigid bodies that make up the robot. It is a bridge between the Cartesian coordinate spaces of robot end tools[1].It is called inverse kinematics problem to find six angles of the industrial robot corresponding to the given position and attitude of the hand. The inverse kinematics solution is that transformation between the position and attitude and joint variables, which plays a key role in the control of the robot motion analysis, off-line programming, trajectory planning and so on[2].

Due to the complexity of the inverse problem of robot, it is very hard to calculate the algorithm. symbolic and numerical method are included in the inverse kinematics. For most of the bottom kinematics design methods of industrial robots, the closed solution can be obtained by algebraic method[3]. The disadvantage of algebraic method is that it needs lots of experience, so the specific robot structure can not simplify the calculation process. the iterative method depends on the initial point and can converge to a single solution, but the convergence speed is limited, consequently, the method can't be controlled in real time.

At present, although PID control technology is widely used in engineering practice, but with the progress of science and technology and the improvement of control quality requirements, the shortcomings of PID control technology are more and more prominent[4]. The traditional PID control is only suitable for the precise model control object, so the control effect of the control object which can not establish the precise model is not very ideal, the parameter setting effect and the adaptability
are both bad. So many experts and scholars use various intelligent algorithms to improve PID control and apply them in different occasions. Therefore, a method to solve the inverse kinematics problem of robot by using rbf-pid adaptive controller method has been proposed.

2. Principle of RBF Neural Network
A three-layer feedforward network with N inputs is RBF neural network, which contains one output. Because the controlled object is multivariable and non-linear in the actual process, the non-linear fitting cannot be satisfied by using the regulation approach of permanent parameter[5]. But it can approach function precisely, and can identify the controlled object, so as to obtain a simple control model. Jacobian matrix is obtained by RBF neural network identification, and PID parameters are adjusted by adaptive algorithm[6].

The RBF neural network's structure is as follows: I input nodes, J hidden nodes and one output node are contained[7].

![Figure 1. RBF neural network.](image)

In the RBF neural network, \( X = [x_1, x_2, \ldots, x_N]^T \) is the input vector of the network, \( H = [h_1, h_2, \ldots, h_j, \ldots, h_m]^T \) is the radial basis vector of the network, and the radial basis function is Gaussian function

\[
G(X_j, C_j) = \exp \left( -\frac{\|X_j - C_j\|^2}{2b^2_j} \right), (j = 1, 2, \ldots, m).
\]

where, \( C_j \) is the center vector of the first hidden node in the network;
\( C_j = [C_{j1}, C_{j2}, \ldots, C_{jn}]^T \) \( i = 1, 2, \ldots, n \) is the basic broadband parameter of the hidden node \( j \), and the variables are greater than 0.

The linear combination of the output of the identified hidden nodes is as follow:

\[
y_m(k) = w_1h_1 + w_2h_2 + \cdots + w_mh_m
\]

Network identification performance index function is as follow:

\[
J(k) = 0.5((y(k) - y_m(k))^2)
\]

To decrease the error between the expected output and the actual output of RBF network, the output weight \( w_j \) of each network parameter learning iteration is:

\[
w_j = w_j(k-1) + \eta_{rbf}(y(k) - y_m(k))h_j + \alpha(w_j(k-1) - w_j(k - 2))
\]

The node base width parameter \( b_j \) is:

\[
\Delta b_j = \eta_{rbf}(y(k) - y_m(k))w_jh_j \frac{\|X_j - C_j\|^2}{b^2_j} 
\]

\[
b_j = b_j(k-1) + \eta_{rbf}\Delta b_j + \alpha(b_j(k-1) - b_j(k - 2))
\]
Node center $C_{ji}$ is:

$$\Delta C_{ji} = (y(k) - y_m(k))w_j \frac{(X-C_j)}{b_j^2}$$

$$C_{ji} = C_{ji}(k-1) + \eta_{bf} \Delta C_{ji} + \alpha(C_j(k-1) - C_j(k-2))$$

3. Design of RBF-PID Adaptive Controller

The inverse kinematics of robot is a process of solving the joint variables of robot from the known position and pose of robot. The nonlinear system is assumed to be a nonlinear extended regression sliding model[8].

The input of RBF neural network is[9]:

$$X = [x_1(k), x_2(k), \cdots, x_n(k)]^T = [y(k-1), \cdots, y(k-n_y), u(k-d), \cdots, u(k-n_u)]^T$$

Gauss function is the function of excitation layer[10-12]:

$$R_j(x) = \exp\left(-\frac{x-c_j^2}{2b_j^2}\right), j = 1, 2, \cdots, m$$

$c_j = [c_{j1}, c_{j2}, \cdots, c_{jn}]^T$ is the j-th central point, and $b = [b_1, b_2, \cdots, b_m]^T$ is the basis width vector. According to the preceding propagation process of RBF neural network, the output value of neural network can be obtained. In this paper, Gauss function is the excitation function, and the output of hidden layer neuron of neural network is $R_j(x)$, then the output of neural network neuron is:

$$y_m(k) = \sum_{j=1}^{m} w_j (k-1) R_j(x(k))$$

In conclusion, the output of robot RBF-PID adaptive controller is as follow:

$$y_m(k) = \sum_{j=1}^{m} w_j (k-1) R_j(x(k)) \frac{c_{j(n+1)}(k-1)-u(k)}{b_j^2(k-1)}$$

4. Application of RBF-PID in Solving Inverse Kinematics Algorithm of 6-DOF Industrial Robot

This paper verifies the feasibility and effectiveness of RBF-PID algorithm in solving the kinematics. All the position and attitude matrices of the end joints are calculated by the forward kinematics, and any one of them is taken as the end position and attitude matrix t of the inverse kinematics, as shown below:

$$T = \begin{bmatrix}
-0.2803 & 0.3501 & 0.6721 & 800.2568 \\
0.2352 & -0.7021 & 0.5315 & 822.3552 \\
0.8291 & 0.4521 & 0.1503 & 273.2458 \\
0 & 0 & 0 & 1
\end{bmatrix}$$

The value of joint variable $\theta_1 \sim \theta_n$ is obtained by RBF-PID algorithm, $\bar{T}$ can be calculated by robot forward kinematics equation.
It can be seen from the calculation, the error between the attitude matrix corresponding to the joint variables and the given position matrix is less than 0.001. It can be seen that the RBF-PID algorithm can be used to solve the inverse kinematics equation of industrial robot to meet the requirements of positioning accuracy.

5. Conclusion

Based on the RBF-PID algorithm of industrial robot, the kinematics equation of robot end device relative to the frame system is obtained. Furthermore, the kinematic equation is calculated and the solution of the equation is obtained. The results manifest the correctness of the kinematics and lay a foundation for the application of robot in production.

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