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Research on four axis manipulator trajectory tracking Based on RBF Neural Network Algorithm

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Abstract. 1. According to the characteristics of strong coupling tracking and highly nonlinear of four axis stamping robot, this paper based on neural network control theory proposes a manipulator trajectory tracking method based on RBF neural network. The algorithm is that the neural network as a mechanical arm joint servo controller realizes the fast tracking of mechanical arm movement posture. The simulation results show that this algorithm can improve the effectiveness and accuracy of mechanical arm trajectory tracking.

1. Introduction
Robot as a comprehensive means of extending and expanding people's physical and mental will implement the "automation" in the contemporary highest sense. The application and popularization of the robot is changing the human production mode, life style and way of fighting. Stamping robots can be used for automobile, motor, household electrical appliances industry, and stamping equipment constitute a single automatic punching machine and machine automatic stamping production line. Stamping robot abroad has developed rapidly in recent years. Countries such as Britain and America in the stamping production stamping widening the use of robots further improve the single machine and stamping production line automation. Stamping robot in the development of our country is still in its infancy, most of the production enterprises also are in the use of robots. 5. Many enterprises have not even introduced manipulator, also in manual operation.

2. Stamping robot structure
Four axis series stamping robot is consist of two rotary joints and two mobile joints. The two rotary joint axis parallel, and are used for robot main body and the rotation of the end executor motion.; Move up and down two mobile joints used in the robot main body and telescopic motion robot arm. Basic parameters such as the basic parameters of the robot are shown in table 1

| number | Technical indicators | stamping robot |
|--------|----------------------|----------------|
| 1      | Arm form             | Four axis      |
| 2      | Vertical range / mm  | 400 mm         |
| 3      | Level range / mm     | 1000           |
| 4      | Grab parts maximum weight /kg | 8kg |
Each robot joint transmission way is as follows: joint 1, the rotation of the motor is transferred by synchronous belt, ball screw mechanism will motor rotational motion into straight lifting movement; 2 joints by synchronous belt transfer the rotation of the motor to the input end of the harmonic reducer, the output of the harmonic reducer connection rotation and robot arm, implementation main body rotation. 3 joints are connected by a synchronous belt transfer the rotation of the motor to in synchronization with the components of the movement, to realize the telescopic linear motion of the robot arm; Joint 4 motor machine of decelerate of planet of meter rotary motion and synchronous belt drive.

Four joint robot driven by ac servo motor, combined with the feature of the structure of the robot, in the periodic motion of the robot, according to the parameters of the drive motor and the structure characteristics of the robot body, calculate each joint movement speed and output force (moment) limit, as shown in table 2.

| Parameter               | Axis | Technical indicators |
|-------------------------|------|----------------------|
| Range of motion         | S    | (±140°)              |
|                         | L    | (-40°, +85°)         |
|                         | U    | (-15°, +70°)         |
|                         | T    | (±360°)              |
| Maximum speed           | S    | 148.8°/s             |
|                         | L    | 99°/s                |
|                         | U    | 148.8°/s             |
|                         | T    | 225°/s               |

### 3. The robot dynamics model

In 1955, Denavit and Hartenberg in "ASME Journal of Applied Mechanics" published a paper, then use that this paper for the representation and modeling for the robot, and deduced the equation of motion, this has become a robot and the robot motion modeling method of standard. Denavit and Hartenberg (D_H) model of the robot modeling connecting rods and joints of a very simple method, can be used in any robot configuration, regardless of the structure of the robot how to order and complexity. Assuming that the robot is composed of a series of joints and connecting rod. These joints may be sliding (linear) or rotation (rotation), they can be placed in any order and in any plane. The length of the connecting rod can be arbitrary (including zero), it can be bent or distorted, may also at any plane. So any set of joints and connecting rod can constitute a want to model and represent the robot.

Based on d-h notation for each joint to specify a reference coordinate system, then, to determine from a joint to the next joint (a coordinate system to the next) for transformation. If will from the base to the first joint, again from the first joints to the second joint until in the end all the transformation of a joint together, we get the total transformation matrix of the robot.

In the case of robot arm of a connecting rod. On both ends of the connecting rod n relevant section \( n \) and \( n + 1 \). The connecting rod by two geometric parameters: the connecting rod length and Angle of twist. Because at the ends of the connecting rod joints respectively have their own joint axis, normally the two axis is spatial straight lines in different planes, then the two straight lines in different planes of the common normal of long an is the connecting rod length, the Angle between two straight lines in different planes \( n \) is the connecting rod torsion Angle.

On the base of the robot, can start from the first joint transform to the second joint, and then to the third... To the robot's hand, and ultimately to the end of the actuator. If convert each defined, it can be said many transformation matrix...

Total transformation between the base of the robot and the hand is as follows:

\[
^{R} T_{H} = ^{R} T_{1}^{1} T_{2}^{2} T_{3}^{3} \cdots ^{n} T_{n} = A_{1} A_{2} A_{3} \cdots A_{n}
\]
Where $n$ is the number of joints.

Through right by said four movement of four matrix transformation matrix will be given $A$, in turn, the movement of the matrix $A$. Because all the transformation is relative to the current coordinate system (that is, they are relative to the current local coordinate system to measure and implementation), so all of the matrix are right. And the results are as follows:

$$
^nT_{a+1} = A_{a+1} = Rot(z, \theta_{n+1}) \times Tran(0,0,d_{a+1}) \times Tran(a_{n+1},0,0) \times Rot(x,a_{n+1})
$$

$$
A_{a+1} = \begin{bmatrix}
C\theta_{n+1} & -S\theta_{n+1} & 0 & 0 \\
S\theta_{n+1} & C\theta_{n+1} & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & a_{n+1} \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
0 & C\alpha_{n+1} & -S\alpha_{n+1} & 0 \\
0 & S\alpha_{n+1} & C\alpha_{n+1} & 0 \\
0 & S\alpha_{n+1} & C\alpha_{n+1} & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

$$
(2)
$$

4. Stamping robot trajectory tracking based on RBF neural network

The main purpose of the robot trajectory tracking control system is through a given drive moment of each joint, makes the robot's position, speed and so on ideal state variables to track the given trajectory. With general mechanical system, when determine the structure and the mechanical parameters of the robot, the dynamic characteristics of mathematical model to describe the dynamics equation. Therefore, the design method of the automatic control theory can be used provided, using the method based on mathematical model of the robot controller is designed. But in actual engineering, due to the robot system is a nonlinear and uncertainty, it is difficult to get accurate mathematical model of the robot. Using the neural networks, which can realize the accurate approximation of the unknown part of the robot dynamics equation, so as to realize control without model.

In the structure of RBF network, as $X = [x_1, x_2, \ldots, x_n]^T$ the input vector of the network. A radial basis vectors $H = [h_1, \ldots, h_m]^T$ of the RBF network, including $h_j$ for the gaussian basis function:

$$
h_j = \exp(-\frac{\|X-C_j\|^2}{2b_j^2}), j = 1, 2, \ldots, m
$$

The first node of network center vector to $C_j = [c_{j1}, \ldots, c_{jn}]$, $i = 1, 2, \ldots, n$.

Assumes that weights $W$, approximating function $f(x)$ ideal RBF network output is:

$$
f = Wh(x) + \varepsilon(x)
$$

Among them $W$ is the weight vectors of the network, $h = [h_1, h_2, \ldots, h_n]^T$, $\varepsilon(x)$ is approximation error, $\varepsilon(x) < \varepsilon_N(x)$.

Set $n$ joint manipulator equation is:

$$
M(q)q + C(q, \dot{q})\dot{q} + G(q) + F(q) + \tau_d = \tau
$$

The $M(q)$ order for positive definite inertia matrix. $C(q, \dot{q})$ to order inertia matrix, which $G(q)$ $n \times 1$ order inertia vector, $F(q)$ friction, $\tau_d$ for the unknown external disturbance, $\tau$ as control input.
The tracking error is:
\[ e(t) = q_d(t) - q(t) \]

Define the error function is:
\[ r = e + \Lambda e \]

Among them, \( \Lambda = \Lambda^T > 0 \)
\[ \dot{q} = -r + q_d + \Lambda e \]

\[ M \ddot{r} = M(q_d - q + \Lambda e) = M(q_d + \Lambda e) - M \ddot{q} \]
\[ = M(q_d + \Lambda e) + C + G + F + \tau_d - \tau \]
\[ = M(q_d + \Lambda e) - Cr + C(q_d + \Lambda e) + G + F + \tau_d - \tau \]
\[ = -Cr - \tau + f + \tau_d \]

Where \( f(x) = M(q_d + \Lambda e) + C(q_d + \Lambda e) + G + F \)

In practical engineering, the \( f \) model uncertainties are unknown, therefore, need to \( f \) is approximated to uncertainties.

5. Simulation discussion

Choose robot manipulator system, its dynamic model is:
\[ \tau = M(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) + F(q) + \tau_d = \tau \]

Where
\[ M(q) = \begin{bmatrix} p_1 + p_2 + 2 p_3 \cos q_2 & p_2 + p_3 \cos q_2 \\ p_2 + p_3 \cos q_2 & p_2 \end{bmatrix} \]
\[ V(q, \dot{q}) = \begin{bmatrix} -p_3 q_2 \sin q_2 & -p_3 (q_1 + q_2) \sin q_2 \\ p_3 q_1 \sin q_2 & 0 \end{bmatrix} \]
\[ G(q) = \begin{bmatrix} p_4 g \cos q_1 + p_5 g \cos(q_1 + q_2) \\ p_5 g \cos(p_1 + p_2) \end{bmatrix} \]
\[ F(q) = 0.02 \text{sgn}(q) \]
\[ \tau_d = [0.2 \sin(t) \ 0.2 \sin(t)]^T \]

Taking \( P = [p_1, p_2, p_3, p_4, p_5] = [2.9, 0.76, 0.87, 3.04, 0.87], b = 0.20, z = [e \ e \ q_d \ \dot{q_d}] \)

Using Simulink and S function to the design of the control system, the system simulation results are shown below:
6. Conclusions
Due to the mechanical arm joint control system has the characteristics of nonlinear and parameter changes, the traditional control method based on linear time-invariant systems are difficult to obtain ideal control effect. Therefore, only using the advanced control method can improve dynamic characteristic of the controlled object, and improve the quality of the control. The simulation case shows that the adaptive control method adopted in this paper is effective and feasible, and has a certain reference value in mechanical arm joint control. In the simulation, figure 1 shows the mechanical arm joint Angle on the desired trajectory tracking performance. So the neural network control good intelligent control used in the mechanical arm.

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