A Study on Control Algorithm for Robots with Multi-degree of Freedom

Kexin Lan

School of electrical and information engineering, Beijing university of civil engineering and architecture, Beijing, 100044, China
kexin_lan@126.com

Abstract. Robotics, a synthetic discipline developed in recent years, is the advanced hot spot of academic research at present. As the important branch of robots, robots with multi-degree of freedom are similar with human beings in intelligence, behaviors and appearance. A robot with multi-degree of freedom can imitate some simple movements of human beings. This kind of robot has many joints and a complex control circuit, and if it owns some functions human beings do not have, its control circuit will be more complex. In this thesis, the model for dynamics of robots with multi-degree of freedom is built based on lagrangian function, and the control law of robots with multi-degree of freedom is designed. Additionally, in Matlab, the numerical model of robots with six degrees of freedom is built according to the method of Joint-link parametric, which verifies the correctness of parametric of robots and the kinematic formula.

1. Introduction

Robots, the greatest invention by human beings nowadays, especially in the 21st century, are the advanced hot spots in academic and industrial circles. Robots show the breakthroughs and achievements in many disciplines so far, especially in information technology and control technology, which represents the latest innovation in the field of control automation with a focus on electromechanics. Many scholars consider that with the development of intelligent robots, it is necessary to apply this technology into the productive enterprise of socialist development and our daily life to take unique advantages of intelligent robots. Instead of being the simple industrial automation devices, robots should take the place of human labor to a greater extent. Only in this way, can we make profits from robots rather than simply treat them as lab products, which can promote the development of more disciplines and all-round technologies and make robotics a more active and attractive research field.

Robots with multi-degree of freedom, the important branch of robots, have the similar appearance and walking function with human beings, equipped with some intelligent functions such as vision and hearing. As a kind of service robots, robots with multi-degree of freedom can move automatically in a certain environment and communicate with human beings. In the cognition to robots, robots more like human beings means that the research is more successful. Researchers in the field of robotics also dream of inventing a robot similar with human beings in behaviors. Unlike the common robots, robots with multi-degree of freedom are equipped with flexible pedestrian system, so they can go anywhere they want to at any time including those places and even corners that common people are hard to access to, and then they will do the given tasks. According to the analysis of studies about bionics and mechanics, though robots with multi-degree of freedom, also a kind of mobile robots, show more
outstanding advantages and superiority than wheeled robots and tracked robots.

2. Motion Analysis on Robots with Multi-degree of Freedom

The robots with multi-degree of freedom studied by this thesis can be simplified as a model with seven connecting rods, which is shown as below, but in the thesis, only six degrees of freedom are considered. The joint at the very bottom with two degrees of freedom can do a simple planar motion while the upper joint only has one rotational freedom and the top joint has three degrees of freedom. In the single-step cycle shown as the figure below, the right leg is the supporting leg while the left leg is the swinging leg. The original point of the fixed reference coordinate system is at the central point of the sole of the supporting leg. The positive direction of the axis is the direction of forward motion and the positive direction of the axis is perpendicular to the ground. The axis of rotation of the ankle joint with two degrees of freedom is along the direction of the axis, the axis of rotation of knee joint is along the direction of the axis, and the axis of rotation of skeleton joint with three degrees of freedom is respectively along x-axis, y-axis and z-axis. The length of each connecting rod is $l_i (i = 1, 2, 3, 4, 5)$.

![Figure 1 The motion model of a robot](image)

2.1 Forward Motion

$$R(t) = R[x_1(t), y_1(t), z_1(t), \theta_1(t), x_2(t), y_2(t), z_2(t), \theta_2(t)]$$

When a robot is walking, it is required that the x-coordinate and the z-coordinate of two skeleton joints should be equal all the time. In addition, on the hip joint of the swinging leg, the freedom of the axis of rotation along y-axis is not deflected. The line in the front and the line in the back end of the sole of the swinging leg should be parallel to the ground all the time. Therefore, the vector quantity of the position of a robot at a certain time can be shown as following: where $x_1(t), y_1(t)$ and $z_1(t)$ represent the three-dimensional coordinate of the supporting foot joint in the relative coordinate system and $\theta_1(t)$ is the front rake of the supporting leg while $x_2(t), y_2(t)$ and $z_2(t)$ represent the three-dimensional coordinate of the swinging foot joint in the relative coordinate system and $\theta_2(t)$ is the front rake of the swinging leg.

It is assumed that when a robot is walking forward on the ground, the single-step cycle is T, the strike is K. According to the walking periodic repetition requirement, we can assume that the expected position and speed of a robot at the initial time and the terminal time of the single-step cycle are shown as following:
2.2 Climbing Motion

During the process of climbing, it is required that x-coordinate and z-coordinate of two skeleton joints should be upward and parallel all the time. On the hip joint of the swinging leg, if lines in the front and the back-end of the sole of the swinging leg are paralleled to the slope surface all the time, the axis of rotation along y-direction will not be deflected. Therefore, the position vector of a robot on any slope at any time can be expressed as:

\[
\mathbf{R}(t) = \begin{bmatrix} x_h(0), & 0, & z_h(0), & \theta_h(0), & -\frac{E}{2}, & l_4, & l_1, & 0 \end{bmatrix}^T
\]

\[
\dot{\mathbf{R}}(t) = \begin{bmatrix} \dot{x}_h(0), & \dot{y}_h(0), & \dot{z}_h(0), & \dot{\theta}_h(0), & \dot{x}_f(0), & \dot{y}_f(0), & \dot{z}_f(0), & \dot{\theta}_f(0) \end{bmatrix}^T
\]

\[
\mathbf{R}(t_e) = \begin{bmatrix} \frac{E}{2} + x_h(0), & 0, & z_h(0), & \frac{E}{2}, & l_4, & l_1, & 0 \end{bmatrix}^T
\]

\[
\dot{\mathbf{R}}(t_e) = \begin{bmatrix} \dot{x}_h(0), & -\dot{y}_h(0), & \dot{z}_h(0), & 0, & 0, & 0, & 0 \end{bmatrix}^T
\]

Assumed that the single-step cycle of the climbing motion is \( T \), it needs different calculation to dead weight and inertia force. Therefore, when the stride is \( K \), compared with the forward motion, the accelerated speed in the vertical direction should be considered according to the requirement of the repetition of walking cycle.

2.3 Hopping Motion

During the process of hopping motion, it is required that x-coordinate and y-coordinate of two skeleton joints should be upward and parallel to the and parallel all the time. On the hip joint of the swinging leg, if lines in the front and the back-end of the sole of the swinging leg are paralleled to the slope surface all the time, the axis of rotation along z-direction will not be deflected. Therefore, the position vector of a robot in any given height of hopping at any time can be expressed as:

\[
\mathbf{R}(t, h) = \begin{bmatrix} x_1(t, h), & y_1(t, h), & z_1(t, h), & \theta_1(t, h), & x_2(t, h), & y_2(t, h), & z_2(t, h), & \theta_2(t, h) \end{bmatrix}^T
\]

where \( x_1(t, h), y_1(t, h) \) with \( z_1(t, h) \) refers to the three-dimensional coordinate of the joint of the supporting leg in the relative coordinate system when the hopping height is \( h \). \( \theta_1(t, h) \) refers to the top rake of the supporting leg when the slope angle is \( \alpha \). \( x_2(t, h), y_2(t, h) \) with \( z_2(t, h) \) refers to the three-dimensional coordinate of the joint of the swinging leg in the relative coordinate system when the hopping height is \( h \). \( \theta_2(t, h) \) refers to the top rake of the swinging leg when the hopping height is \( h \).
Assumed that the single-step cycle of the hopping motion is \( T \), it needs different calculation to dead weight and inertia force. Therefore, when the height is \( h \), compared with the forward motion, the accelerated speed in the vertical direction should be considered according to the requirement of the repetition of walking cycle.

3. Design on Control System of Robots with Multi-degree of Freedom

3.1 Control Model Algorithm

Fuzzy control, not depend on the mathematical model of the object, determines the control behaviors by showing the control experiences of experts. It has a good robustness. However, the fuzzy control based on experts’ experiences without learning ability, its rule base and defined membership function cannot be adjusted. Moreover, it is hardly to adjust the uncertainties and changes of the object at any time.

In order to overcome the disadvantages of fuzzy control, neural network is used in it. Neural network does not need to build up a mathematical model, but it has the ability of self-learning. By adjusting parameters and making quantitative expression of input and output relationship of the controller to achieve its goal. In the neural network, any accuracy can approach any nonlinear function to apply it into the areas of system identification and self-adaptation control. There are many disadvantages of neural network such as its poor ability to make qualitative expression of knowledge, no reasoning and inductive skills, and its ambiguous meanings of structure and weight. It is also hard to design and initialize neural network. The combination of fuzzy control and neural network can help the fuzzy control has self-learning ability and improve the reasoning and inductive skills of neural network. At the same time, there are some clear physical meanings of network structure and weight to make the initialization much easier. Therefore, this chapter will make good use of the neural network to realize fuzzy reasoning to form a fuzzy neural network to control the trajectory tracking of robots.

In the industrial production, the controlled object has a variable load and complex interference factors. In order to get a satisfying control effect, PID parameter needs to be debugged on line continuously. There is no mathematical model and rules which can follow. At present, some control theories like self-adaptation control, self-tuning control and optimum control can overcome the weakness of non-linearity of the system and improve the performance of a mediator though they are based on the accuracy. In the mathematical model, the algorithm is complex with a large amount of calculation, but its real-time effect is worse than PID. The basic theory and method of fuzzy mathematics are used. Fuzzy sets represent the rule condition and operation. Fuzzy control rules and relative information are stored in the knowledge base. According to the actual situation of the control system, fuzzy reasoning is used to make the optimum adjustment to PID parameter.

3.2 Algorithm Implementation Based on Matlab

In the environment of matlab, a link object in Robotics v9.10 to describe an industrial robot with connecting rods. The format of the function call of ‘link’is \( L = \text{LINK}([\theta \ d \ a \sigma\Sigma], \text{'standard'}) \) and \( \theta \) represents the included angle of connecting rod \( \theta \). In the format, \( d \) refers to the distance of connecting rod, \( a \), the length of connecting rod, \( \alpha \), the torsional angle of connecting rod, \( \Sigma \), the type of joint, and the sigma value of the rotational joint is 0 while the sigma value of prismatic joint is 1. ‘Standard’ means the adoption of standard joint parameter and ‘modified’ means the adoption of corrected parameter. The parameter of connecting rod got from the last chapter is used to build a model for robots with multi-degree of freedom in matlab. The modeling program is shown as following:

\[
\begin{align*}
L(1) &= \text{Link}([0 0 0.1 \ -\pi/2 0],\text{'standard'}); \\
L(2) &= \text{Link}([0 0 0.222 0 0],\text{'standard'}); \\
L(3) &= \text{Link}([0 0 0 \ -\pi/2 0], \text{'standard'}); \\
L(4) &= \text{Link}([0 0.253 0 \pi/2 0], \text{'standard'}); \\
L(5) &= \text{Link}([0 0 0 \ -\pi/2 0], \text{'standard'}); \\
\end{align*}
\]
L(6) = Link([0 0 0 0 0], 'standard');
robot = Serial Link(L, 'name', 'Industrial Robots ');
q A0=[0 0 0 0 0 0];
figure(1);plot(robot, q A0);
TA0=robot.fkine(q A0);

![Diagram of Matlab program](image)

Figure 2. The simulated figure of Matlab program

The program of control algorithm is shown as following:

```c++
void control algorithm()
{
    int i, j;
    float position_error_derivative;
    if (position_error > position_error_threshold) // Use Fuzzy PD controller to evaluate the set point of the speed controller
    {
        position_error_derivative = position_error - position_error - position_error - 1; // Calculate e(n)
        i = (int) (position_error * domain_coefficient1); // Transform the scale of e(n) and quantify e(n)
        j = (int) ((position_error_derivative) * domain_coefficient2); // Transform the scale of e(n) and quantify e(n)
        speed_set_value = fuzzy_control[lookup table[i][j]] / domain_coefficient3; // Look up the fuzzy list to evaluate Uf(n)
    }
    else
    {
        // Use the PID controller of single neural self-adaptive control to evaluate the set point of the speed controller
        x[0] = position_error - position_error - position_error - 1; // Calculate the input quantity of single-neuron
        x[1] = position_error - position_error;
        x[2] = position_error - 2 * position_error - position_error - 2;
        wx n = 0;
        for (i = 0; i < 3; i++) // Calculate the input quantity of single-neuron transformation function
        {wx_n += w[i] * x_n[i];
        speed_setes_value = speed_set value + wx n;
    }
```
if(speed_set value n>speed set value max) // Calculate the output quantity of single-neuron transformation function Un(n)
{
  speed_set value n=speed set value max;
}
if(speed set value n<speed set value min)
{
  speed_set value n=speed set value_min;
}
speed_set value nl=speed_set value n;  //U-(n−1)=U-(n)
w ← study(0);

//}Correct the weight of neuron along the negative gradient direction of E for one time
position error n2=position error n1;//ee(n−2)=ee(n−1)
position error nl=position error n;  //ee(n−1)=ee(n)

4. Conclusion and Expectation
Robots with multi-degree of freedom is the integration of some basic subjects and high technologies, representing the cutting-edge technology of robots. As the hot spot in the field of technological research nowadays, the robot with multi-degree of freedom is not only the important symbol of national comprehensive level of high technology, but also plays an important role in human production and daily life. This thesis studies on the kinetic model of robots with multi-degree of freedom and makes an mechanical analysis on forward motion, climbing motion and hopping motion. Based on the analysis, it discusses the algorithm of the control model of robots with multi-degree of freedom and simulates the matlab environment to verify the possibility for robots with multi-degree of freedom to finish the motion mentioned above.

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