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Application of Robot Dynamic Tracking Predictive Control in Mechanical Control Engineering Course

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Abstract: With the continuous development of science and technology, the application scope of robots has expanded from simple tasks to more complex and diverse fields. The application of mechanical control engineering courses in robotics is very broad. For example, the application of robots in complex scenarios combines multiple sensor data to improve the accuracy and robustness of robots. In this paper, a prediction model with angle as variable is designed to improve the accuracy and robustness of the robot in the scenario of tracking dynamic target objects. By obtaining the position information of the first three joints of the robot arm, the expected position difference between the robot arm and the target object is set as the cost function. The multi-sensor data is used for iteration to minimize the objective function. The robot arm outputs the optimal control strategy in a dynamic environment to realize the control method in the process of dynamically tracking the target.

1. Introduction

Mechanical control engineering is more and more widely used in industry. In order to strengthen students' application of control theory in the field of robot, this paper takes robot as the object of case analysis. With the rapid development of global trams, the recycling and remanufacturing of a large number of discarded batteries has gradually become an important means to support the circular economy. At the same time, in order to avoid that the battery disassembly toxic substances harm the human body, collaborative robots are gradually applied to the battery disassembly process. The multi-sensor technology, deep neural networks and other methods are used to ensure the stability of the robot system control process. Patni et al. installed a force/moment sensor on a robotic gripper and converted the gripper effort/position curve into a stress/strain curve to assess the stiffness/elasticity of the object [1]. Singh et al. perform sensor fusion of inertial measurement units and UWB devices, and use the fusion data to estimate the position and orientation of the robot through a neural network to provide indoor positioning accuracy [2]. Angleraud et al. proposed a sensor-based method to identify human-robot interaction, which solves the interaction problem that human and robot cannot share the task background and the occurrence environment under the conditions of some industrial environments such as noise and dirt [3]. Deng et al. proposed a new hawk-eye multi-camera sensor significance detection method. Through the cooperative work of multiple camera sensors, prominent targets can be checked, which has a strong inhibition effect on moving background interference [4]。

To sum up, multi-sensor signals play a very important role in modern engineering technology. Multi-sensor signal fusion technology improves the performance and reliability of intelligent systems by improving data quality and system robustness, enhancing environment perception, enriching feature extraction, and supporting complex decision making. Multi-sensor signals in the robot system not only improve the environment perception and positioning accuracy, but also enhance the decision-making ability and system reliability, thus significantly improving the overall performance of the robot and the task execution ability. The multi-sensor fusion becomes the key technology in the design of modern robot system.

In the above applications, although multi-sensors can improve and help the robot system in some aspects, the robustness of control and tracking accuracy are still a challenge in the dynamic target tracking environment due to the high nonlinearity of the robot arm system. In this paper, the method of tracking target object under dynamic environment is studied, and a model predictive control method with position sensor and angle position as variables is designed.

2. Robot dynamic tracking control method

2.1. Establishment of Lagrange dynamic model

The kinetic parameters such as moment of inertia and mass of the first three joints of the manipulator are large, and the nonlinear effects are obvious, while the kinetic parameters of the last three joints are small. Within the allowable error range, simplifying the dynamic modeling of the six-degree-of-freedom manipulator to the dynamic model of the first three degrees of freedom can obtain a more accurate dynamic model and reduce the calculation amount. The simplified UR5 model is shown in Figure 1.

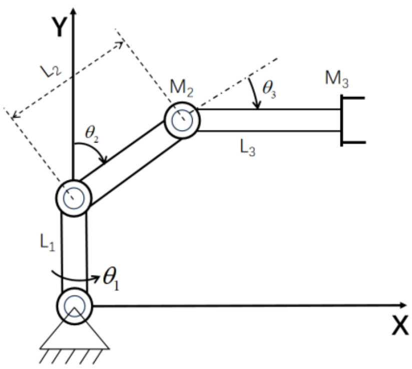

Figure 1: UR5 model diagram.

The dynamics model of UR5 manipulator arm is a very complex nonlinear model. In order to reduce error probability, the Lagrangian mechanics method based on the differentiation of energy term to system variables and time is adopted to view the system from the perspective of energy.

2.2. Prediction Models with angles as a variable control

The first three axes of the robotic arm are controlled by predictive model. Firstly, the feedback linearization control is designed to make the system linear. After the model linearization, the model predictive control is designed. The controller can finally be regarded as a nonlinear variable magnitude cascade controller, and the flow chart is shown in Figure 2.

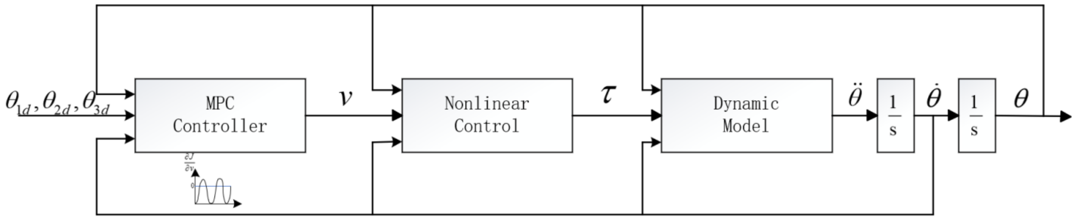

Figure 2: Closed-loop framework of model predictive control.

Feedback linearization design is to transform the nonlinear dynamics of the manipulator into full or partial linear dynamics, which is easy to stabilize the system in a linear control controller. A feedback linearization control method is designed for the front three axis dynamic model of the manipulator. Differentiate the output Y of the system until the input of the system τ appears, and the output Y is expressed as follows:

$$\ddot{Y} = \ddot{\theta} = M(\theta)^{-1}(-C(\theta,\dot{\theta}) - G(\theta) + \tau) = v \tag{1}$$

The relation between synthetic control and actual control torque is obtained by the following expression:

$$\tau = M(\theta)v + C(\theta,\dot{\theta}) + G(\theta) \tag{2}$$

The nonlinear system is transformed into the linear double integral system of the front three-axis dynamic model of the manipulator, and the linear system of the front three-axis joint variables is obtained.

Three decoupled linear systems can be obtained by feedback linearization of the nonlinear manipulator system:

$$\begin{cases} \ddot{\theta}_1 = v_1 \\ \ddot{\theta}_2 = v_2 \\ \ddot{\theta}_3 = v_3 \end{cases} \tag{3}$$

Design an MPC controller for the first link of the manipulator. The controller design of the second link and the third link of the robot arm is the same. Here, we need to make the assumption that the acceleration is constant over the time interval [t, t+h]. h is the predicted horizontal time. Based on the above assumptions, the prediction model is as follows:

$$\begin{cases} \dot{\theta}_1(t+h) = v_1 h + \dot{\theta}_1(t) \\ \theta_1(t+h) = \frac{1}{2} v_1 h^2 + \dot{\theta}_1(t)h + \theta_1(t) \end{cases} \tag{4}$$

The expected angle of the first link is obtained by the inverse solution of the expected trajectory, and the expected angle of the second and third links is the same. The joint angle information of the current robot is obtained by the sensor. Define the quadratic cost function as:

$$J = e_1^2(t+h) + r\dot{e}_1^2(t+h) \tag{5}$$

where $e_1(t+h) = \theta_{1d} - \theta_1(t+h)$ is predict joint angle error, $\dot{e}_1(t+h) = 0 - \dot{\theta}_1(t+h)$ is the predicted joint angular velocity error, the horizontal time *h* and the weight *r* are the control parameters. Optimal expression is:

$$v_1 = k_1(\theta_{1d} - \theta_1(t)) - k_2\dot{\theta}_1(t) \tag{6}$$

$$k_1 = \frac{2}{h^2 + 4r}, k_2 = \frac{2h^2 + 4r}{h^3 + 4rh} \tag{7}$$

Although the acceleration is not constant in $[t,t+h]$, the control law is still suitable for the application of trajectory tracking. Based on the above, the control law of the optimal solution is:

$$v_1(t) = k_1(\theta_{1d}(t) - \theta_2(t)) - k_2\dot{\theta}_1(t) \tag{8}$$

$$v_2(t) = k_1(\theta_{2d}(t) - \theta_2(t)) - k_2\dot{\theta}_2(t) \tag{9}$$

$$v_3(t) = k_1(\theta_{3d}(t) - \theta_3(t)) - k_2\dot{\theta}_3(t) \tag{10}$$

2.3. Experimental simulation

A scene of a robotic arm dynamically tracking and grabbing objects on the conveyor belt is built, and the feasibility of the method is proved through simulation. The simulation process and scene diagram are shown in Figure 3.

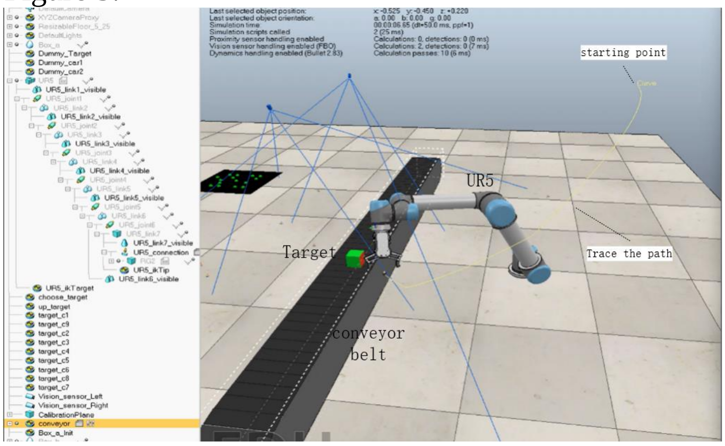

Figure 3: Simulation process and scene diagram

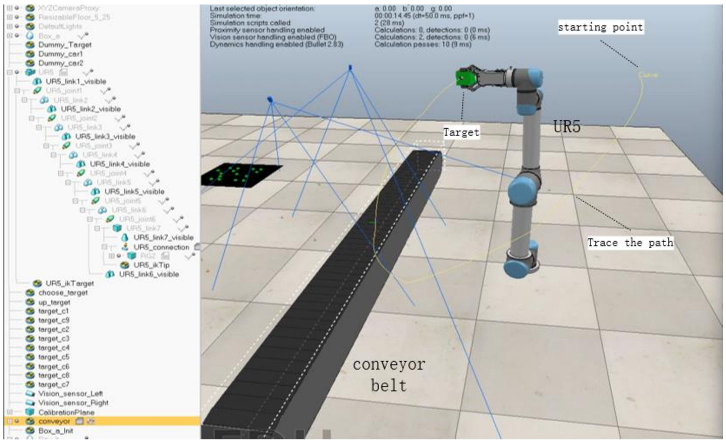

Figure 4: The process of grasping objects.

At the beginning, there is a large gap between the robotic arm and the target object. With the data of the sensor and the continuous iteration of the algorithm, the robotic arm constantly approaches the target object and finally catches the target object moving on the conveyor belt as shown in Figure 4.

The accurate value of the position sensor is cooperated with the control algorithm, so that the robot has more development possibilities in the dynamic working scene. In this paper, we discuss the iterative cooperation between the control algorithm of the robot arm and the sensor signal, and carry out secondary development and design a possibility in a specific scene.

3. Conclusion

In this study, we deeply discuss the application of sensor signals in model predictive control algorithm to control robots. Because sensor signals can provide accurate position information, so that it can be combined with many cutting-edge robot control algorithms, and has a very important role in robot system development and industrial automation. The position information fed back by the position sensor can let us know the current position of the robot more accurately, so that the algorithm can use the data to better iterate. The robot can better track the moving target object in the dynamic environment. This study emphasizes the important role of position sensor signals in robot control algorithms, and provides another way for robots to work in complex scenarios. Future research can be deepened in the following aspects:

(1) Algorithm optimization: add the module dealing with interference noise to adapt to more complex work scenarios.

(2) Modeling method: Neural networks can be used for training and fitting to reduce errors caused by modeling.

(3) Application: The method studied in this paper can not only be applied to robot systems, but also to control fields, such as automobiles, drones, etc. More complex data can be used for modeling to achieve technological innovation and migration.

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