Multi-Degree-of-Freedom Manipulator Joint Trajectory Tracking Control Method Based on Decision Tree

Gangyi Gao1,*, Cuixia Ou2, Linian Shi1

1College of Mecanical Engineering, Jingchu University of Technology, Jingmen, Hubei, China, 448000
2College of Mecanical Engineering, Hangzhou Dianzi University, Hangzhou, Zhejiang, China, 310000

*Corresponding author e-mail: gangyi126@jcut.edu.cn

Abstract. For industrial-grade manipulators, the study of trajectory tracking control issues provides an important guarantee for accurate and safe work. Therefore, the trajectory control input driving torque can meet the requirements of the robot arm to accurately track a given target trajectory, and the process of building a decision tree is a process of dividing the feature space. For a given training data set, a set of if-then is summarized the rule of. Based on this, this paper launches the research of multi-degree-of-freedom manipulator joint trajectory tracking control method based on decision tree. Based on the established kinematics and dynamics model of the manipulator, this paper uses a proportional-integral-derivative (PID) sliding mode controller based on the sliding mode surface of the manipulator to perform the trajectory tracking control of the end of the manipulator, and the simulation results of the improved sliding mode control are compared with the simulation results of the improved sliding mode control. The simulation results of the PID controller and the traditional sliding mode controller are compared. This paper finally verifies the effectiveness of the proposed new sliding mode controller based on the expanded state observer through the experimental platform. The speed and chattering problems of the trajectory tracking at the end of the manipulator are better than those of the controller on the experimental platform. Finally, this paper adopts the sliding mode variable structure control strategy combining the double-power reaching law and the improved terminal sliding mode surface to study the trajectory tracking control of the planar two-degree-of-freedom manipulator.

Keywords: Decision Tree, Multi-Degree-of-Freedom Manipulator, Trajectory Tracking, Dynamic Model

1. Introduction
At this stage, there is a big gap between my country and foreign countries in the theoretical discovery of industrial robot weapons and the implementation of robotic arm mechanics. Our country must define the basic technology of robotic weapons and vigorously support the development of related...
industries [1-2]. In order to develop our country's industrial robot weapons, the discovery of related technologies must focus on the following aspects. The first is the main body of the robotic arm, which contains related technologies such as machining, assembly and testing [3-4]. The second is some common technologies that need to be overcome, such as chattering problems, noise problems and mechanical hand sealing problems. Next, there are interface technologies related to robotic arms, including mechatronics issues, the interface between software and hardware, and the interface between software [5-6]. Finally, there are some bus standards, communication technology, simulation and offline programming. The most difficult technical problem that Chinese industrial operators must overcome is the gearbox. So far, our country has not mass produced precision gearboxes with high stability, high precision and long life [7-8].

In the research on the trajectory tracking control method of multi-degree-of-freedom manipulator arm based on decision tree, many scholars have studied it and achieved good results. For example, Yanbiao LI compares the accuracy of neural network RBF and MLP in obtaining the inverse kinematics solution of the six degrees of freedom of the operator, and can find that the calculation accuracy of neural network RBF is higher than that of MLP, and the calculation time is faster [9]. Wang H studied the trajectory design problem of the robotic arm constrained by the optimal time, and emphasized the continuity of the acceleration derivative, using high-order polynomial interpolation methods to study the trajectory design problem [10].

In order to better carry out the research, the current status of multi-degree-of-freedom manipulator joint trajectory tracking research is briefly summarized, and the main problems existing in multi-degree-of-freedom manipulator joint trajectory tracking control are analyzed. This paper uses 30 cascaded deep decision trees for the classifier when verifying feature subsets. This paper proposes two control strategies for the kinematic model and dynamics model of the industrial manipulator, and conducts theoretical simulation research on the basis of the 3-DOF space manipulator. To this end, in order to verify the effectiveness of the measures in this article, we conducted an in-depth analysis of the surveyed data.

2. Research on tracking control method of multi-degree-of-freedom manipulator joint trajectory based on decision tree

2.1. Current status of research on multi-degree-of-freedom manipulator joint trajectory tracking

The purpose of industrial robot arm trajectory detection is to control state variables (such as hinge position and robot arm speed) based on the given control input torque of each link, so that it can accurately monitor the given trajectory. The way is:

(1) The operator's body cannot bear a large control torque for a long time. Even if it can be controlled, the damage to the engine is huge, which will reduce the use. At the same time, the accuracy of PID control algorithm is low [11]. When the position and speed error of the manipulator is required to be small, the PID algorithm will no longer be applicable. This shows that PID control has some limitations.

(2) Based on powerful control: Because the robotic arm system has high uncertainty in the modeling process, and the robust control can overcome these weaknesses, the robust control should not only consider the typical dynamic model of the robotic arm, but also consider [12]. The operator's other uncertain factors can make the operator's system maintain a certain degree of strength and strong stability in the case of greater external interference.

(3) Sliding control based on variable structure: The sliding mode variable structure control algorithm is mainly integrated in the variable structure, that is, in the dynamic process, according to the actual state of the current system of the operator system, the system is forced to slide according to the specified state, finally, the system slides to the equilibrium point. The design of the slip control law has nothing to do with the parameters and interference of the operator system, that is to say, it is not sensitive to parameter changes and accidental interference, so it is very suitable for non-manipulable operator system linearity.
(4) Based on iterative learning control: Based on the background of industrial robot arm monitoring and control, iterative learning theory was established. Repetitive learning is very suitable for mathematical models with strong nonlinearity and strong coupling, because repetitive learning is not based on precise mathematical models, but similar to strong control. Repetitive learning has powerful processing capabilities in terms of uncertain parameters and requires less progress. In the learning process, how to precisely adjust the learning factors so that the academic performance and accuracy meet the requirements still needs further research.

2.2. Current problems in trajectory tracking control
The main problems currently existing in multi-degree-of-freedom manipulator joint trajectory tracking control:

(1) The tracking accuracy of parallel industrial operators is insufficient to solve the chat effect well. There are few researches on discrete-time systems at present [13]. The operator control system is a standard discrete time control system. All discrete-time systems must consider the use of continuous excitation to ensure system stability.

(2) The application of the D-H parameter method in the analysis of the kinematics model of the manipulator involves the creation of the local coordinate system and the particularity of the resulting transformation matrix. The inverse kinematics solving algorithm must also be optimized to meet the requirements of real-time and efficient tracking. Because it is difficult to create an accurate dynamics model of the mechanical arm combined with various external disturbances, it is difficult to achieve accurate orbit tracking with a control method strictly based on a mathematical model.

(3) When the system starts to slide on the sliding surface of the mold from the initial state, the robot arm will produce severe jitter due to the excessively fast speed [14]. The bus moving back and forth on the surface of the sliding matrix can easily damage the motion and controller of the robot arm system. At present, the variable slip structure algorithm is mainly used for the control of electric motors, power systems and robots. At the same time, it can also be combined with different control objects, using variable slip structure control for control research.

2.3. Kinetic formula
Manipulator dynamics describes the relationship between the control torque of each joint of the manipulator and the rotation angle, angular velocity and angular acceleration of each joint. At present, the most classic method of analyzing manipulator dynamics mainly includes the second type of Rager. Lange function method and Newton-Euler method. The Newton-Euler method uses a three-dimensional vector to describe the angular velocity of each link, while the Lagrangian method uses the derivative of the rotation matrix to describe the angular velocity of the link. In this paper, the dynamic model of the multi-degree-of-freedom manipulator is obtained on the basis of the Lagrangian function method. The Lagrangian function is shown in formula (1):

\[ L(q, \dot{q}) = K - P \]  

(1)

Lagrangian equation: as shown in formula (2):

\[ u_i = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} \]  

(2)

The potential energy \( P \) is defined as the sum of the gravitational potential energy of each connecting rod, and its expression is shown in formula (3):

\[ P = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} m_i g r_{iy} \]  

(3)
3. Experimental research on tracking control method of multi-degree-of-freedom manipulator joint trajectory based on decision tree

3.1. Research materials and experimental design
The maximum redundancy correlation option selection algorithm calculates the information difference through the maximum correlation operator and the minimum redundancy operator, and classifies them according to the size of the information difference. From the largest feature to the smallest feature, the information difference is selected in turn, and then the classifier is used for verification, and the best attribute subset is selected. This classification is the mRMR attribute classification. Because the goal is to train a cost-sensitive deep decision tree for the selected feature subset, and different classifiers correspond to different feature selection results, the classifier used to characterize the subset uses 30 continuous deep decision trees.

The selected detection model training samples are basically the same, the negative tangent positive samples in the training set are eliminated, and several negative samples are added. The final training set contains 17,002 positive samples and 20,007 negative samples. The sample is converted. The final training samples are 17,020 positive samples and 20,070 negative samples. The test set selected 284 positive samples and 120 negative samples, which were self-made outside the training set. The training standard still uses 21*21, and the size of the NPD function below this standard is 167600.

3.2. Analysis method and evaluation content
165,600 attributes are classified according to the information difference between the maximum correlation and the minimum redundancy criteria, and the top 100,000 attributes with large information differences are selected. To select the best subset of features from these 100,000 features, it must be validated by the next classifier and 30 deep waterfall decision trees. The information corresponding to different features is poor. The greater the difference in information, the stronger the correlation between this function and the category, and the less redundancy with other functions.

4. Research and analysis of multi-degree-of-freedom manipulator joint trajectory tracking control method based on decision tree

4.1. Analysis of the selection of excellent feature subsets by the decision number algorithm
Use 30 cascaded deep decision trees to verify the feature subset. Because of the large number of features, the forward feature selection algorithm is slightly modified. For the top 100,000 features with large information difference after sorting, a method of starting from 10,000 features and gradually adding 10,000 features is adopted until it reaches 100,000 features, or the highest classification accuracy is reached for the first time. The test results are shown in Table 1:

| Feature number | Classification accuracy 1 | Classification accuracy 2 |
|----------------|---------------------------|---------------------------|
| 1              | 0.54                      | 0.58                      |
| 2              | 0.57                      | 0.61                      |
| 3              | 0.67                      | 0.63                      |
| 4              | 0.76                      | 0.72                      |
| 5              | 0.74                      | 0.78                      |
| 6              | 0.76                      | 0.80                      |
| 7              | 0.80                      | 0.76                      |
| 8              | 0.79                      | 0.79                      |
| 9              | 0.79                      | 0.83                      |
| 10             | 0.81                      | 0.79                      |
Figure 1. Select the excellent feature subset data

As shown in Figure 1, comparing the classification effect of 100,000 features sorted according to the information difference evaluation function of the maximum correlation and minimum redundancy algorithm, it can be seen from the figure that as the number of features increases before 90,000 features, the classification accuracy rate increased, and the highest point of classification accuracy rate was reached for the first time when the number of features added to 90,000. Therefore, the top 90,000 features after sorting are selected as the excellent feature subset.

4.2. Analysis of the relationship between the number of decision tree nodes and the number of samples in the data set

In the experiment, the number of samples is set to: 200, 400, 600, 800, and 1000, and the performance changes of the comparison algorithm when the data set increases. Figure 2 shows the changes in the number of decision tree nodes as the number of samples increases. summary graph.

Table 2. The relationship between the number of decision tree nodes and the number of samples in the data set

| Algorithm | 200 | 400 | 600 | 800 | 100 |
|-----------|-----|-----|-----|-----|-----|
| WFC4.5    | 55  | 74  | 102 | 110 | 131 |
| DM        | 38  | 43  | 52  | 61  | 75  |
| FR MDT    | 39  | 40  | 49  | 58  | 72  |

Figure 2. The relationship between the number of decision tree nodes and the number of samples in the data set

It can be seen from the Figure 2 that the number of nodes of the WFC4.5 algorithm increases the fastest. When the number of samples increases, the size of the tree increases rapidly, while the increase
of the tree size of the FR MDT algorithm is limited, which can be avoided to a certain extent. The problem of overfitting and repeated selection of attributes.

5. Conclusion
This paper proposes two control strategies for the kinematic model and dynamics model of industrial operators, and conducts theoretical simulation research based on the three-degree-of-freedom spacer operator. The new slider operator designed based on the extended state observer has been applied to the Denso VP6242G experimental platform for experimental verification and analysis. A basic coordinate system is created in the simplified 3-DOF spacer model. The motion model is determined by the position of the operator's end and the center of gravity of each link in the 3D space, and then the dynamic model is determined according to the lagrangian operation method. Based on this model, the simulation results of different control strategies are compared.

Acknowledgments
Fund project: Hubei Provincial Department of Education Science Research Program Project (B2020196); Jingmen City Science and Technology Program Project (2020YFYB051).

References
[1] Wang H, Liu S. Position Servo Control Method for Multi-Degree-of-Freedom Pneumatic Manipulators Based on Delayed Feedback [J]. Automatic Control and Computer Sciences, 2020, 54(1):10-18.
[2] Lou Y, Lin H, Quan P. Robust Adaptive Control of Fully Constrained Cable-Driven Serial Manipulator with Multi-Segment Cables Using Cable Tension Sensor Measurements [J]. Sensors, 2021, 21(5):1623-1624.
[3] Harton DGosselin C. Modelling, trajectory optimisation and prototyping of sequentially actuated manipulators [J]. Robotica, 2018, 37(2):1-19.
[4] Shen C, Chang T H, J Gong. Multi-UAV Interference Coordination via Joint Trajectory and Power Control [J]. IEEE Transactions on Signal Processing, 2020, 68(05):843-858.
[5] Ma X, Zhao Y, Di Y. Trajectory Tracking Control of Robot Manipulators Based on U-Model [J]. Mathematical Problems in Engineering, 2020, 2020(8):1-10.
[6] ZENG, Li, CHEN. Research of Mechanism of Inductive Maglev Spherical Driving Joint [J]. Chinese Journal of Electronics, 2016, 01(25):30-36.
[7] Zheng K, Hu Y, Wu B. Trajectory planning of multi-degree-of-freedom robot with coupling effect [J]. Journal of Mechanical Science and Technology, 2019, 33(1):413-421.
[8] Li L, Bai Z. Study of space manipulator motion analysis based on mathematical modeling method [J]. Journal of Mechanical Engineering Research and Developments, 2017, 40(1):304-310.
[9] Yanbiao L I. Dynamic Modeling with Joint Friction and Research on the Inertia Coupling Property of a 5-PSS/UPU Parallel Manipulator [J]. Journal of Mechanical Engineering, 2019, 55(3):43-44.
[10] Wang H. Space manipulator motion analysis based on mathematical modelling method [J]. Journal of Interdisciplinary Mathematics, 2018, 21(5):1193-1197.
[11] Liang D, Song Y, Sun T. Optimum design of a novel redundantly actuated parallel manipulator with multiple actuation modes for high kinematic and dynamic performance [J]. Nonlinear Dynamics, 2016, 83(1-2):631-658.
[12] Fan, Lv, Lin. Autonomous Operation Method of Multi-DOF Robotic Arm Based on Binocular Vision [J]. Applied Sciences, 2019, 9(24):5294-5295.
[13] Li J, Wang Q. Control system of trajectory tracking of discretely-actuated manipulator based on computed torque method [J]. Journal of Intelligent and Fuzzy Systems, 2020, 38(2):1-10.
[14] J. Baek, M. Jin, S. Han, A new adaptive sliding-mode control scheme for application to robot manipulators [J]. IEEE Transactions on Industrial Electronics, 2016, 63(6): 3628-3637.