Hybrid Manipulator Running Trajectory Prediction Algorithm Based on PLC Fuzzy Control

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Abstract. Aiming at the problem of multi-band motion and multi-joint inflection point of hybrid manipulator, the conventional trajectory prediction algorithm cannot satisfy the fast analysis and accurate control of motion trajectory. This paper proposes a hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control. Based on newton-andrews law, the dynamic model of hybrid manipulator was built, and the dynamics of hybrid manipulator was analyzed and the dynamic characteristics were determined. PLC fuzzy control unit is introduced, based on the kinematics characteristics of hybrid manipulator, the relevant input and output variables of PLC fuzzy control unit are determined, and the fuzzy strategy is implemented and analyzed. The construction of a hybrid manipulator based on fuzzy control is completed. The test data show that the proposed prediction algorithm is better than the conventional prediction algorithm, and the accuracy is improved by 57.42%, which is applicable to the prediction of the operation trajectory of the hybrid manipulator.

Keywords: PLC fuzzy control · Hybrid manipulator · Trajectory · Prediction algorithm

With the continuous development of equipment manufacturing industry, manipulator will replace people to complete repetitive or labor-intensive work. Due to the limitations of different tasks, hybrid manipulator has developed rapidly. However, the conventional trajectory prediction algorithm cannot satisfy the fast analysis and accurate control of motion trajectory of the hybrid manipulator [1]. Therefore, the hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control is proposed. Based on newton-andrews law, the dynamics of hybrid manipulator was analyzed and the dynamic model of hybrid manipulator was built, and the dynamic characteristics were determined according to the dynamic variation parameters. PLC fuzzy control unit is introduced, the relevant input and output variables of PLC fuzzy control unit are determined, and the fuzzy strategy is implemented and analyzed. The construction of the hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control is completed. To ensure the effectiveness of the designed manipulator trajectory prediction algorithm, it's necessary to simulate the manipulator testing environment, two kinds of manipulator trajectory prediction algorithms are used to

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perform the hybrid trajectory prediction analysis test. Test results show that the proposed manipulate trajectory prediction algorithm is highly effective.

1 System Object and Analysis

The objects of hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control mainly includes:

(1) Without relying on high-precision mathematical model analysis, relying on the PLC fuzzy control strategy, it is able to predict and judge the running trajectory of the hybrid manipulator and ensure high prediction accuracy.
(2) Through analysis of the motion of hybrid manipulator structure, the force state is fully understood, the dynamic characteristics are evaluated, and the PLC fuzzy control strategy is applied to determine the domain and parameters of the relevant input and output variables, and the motion trajectory prediction and analysis is performed.
(3) For the hybrid manipulator with multi-band motion and multi-joint inflection points, a general dynamics model is constructed to solve the problem that the conventional trajectory prediction algorithm cannot meet the requirements of rapid analysis and precise grasp of the trajectory.

2 Motion Analysis of Hybrid Manipulator Structure

2.1 Dynamic Model Construction of Hybrid Manipulator

To accurately analyze the trajectory of the hybrid manipulator, the dynamic model of the hybrid manipulator is firstly constructed. The dynamic model construction is based on the dynamic characteristics of the hybrid manipulator. The hybrid manipulator mainly includes three parts: manipulator, electric control and program control. The manipulator mainly completes the task of mechanical operation, which includes grasping unit, joint inflection point unit, kinetic energy providing mechanism, and other auxiliary mechanisms. Grasping unit is a work unit that completes the mechanical task, and the joint inflection point unit ensures that the task arrives safely from point A to point B, usually the traditional manipulator has one inflection point, while the hybrid manipulator can complete more complex work, generally has 2–3 key inflection points [2, 3], which results in great calculation difficulty to conventional trajectory prediction algorithm. Kinetic energy providing mechanism mainly includes the transmission mechanics mechanism such as motor, and provides kinetic energy for the mechanical part. Other auxiliary mechanisms mainly include mechanical lubrication unit, mechanical protection unit. Electric control exerts the control order of program to control the hybrid manipulator as well as to finish special task. Program control edits code according to different programs and control the manipulator according to design requirements.

Provided that the origin of hybrid manipulator with multi-band motion and multi-joint inflection point is O, the length of first-level hybrid manipulator is l_1, the length of second-level hybrid manipulator is l_2, and so on, the maximum head angle of first-level is θ_1, the mass of first-level manipulator is m_1, it's assuming that the mass of manipulator is uniform, with unit distance, the mass of manipulator m_1/l_1. The acceleration of mass center of first-level hybrid manipulator is v_{a1}, uniform motion speed is v_1, inertia tensor is I_1, effort torque is N_1, the acceleration of mass center, uniform motion speed, inertia tensor and effort torque of second-level hybrid manipulator are respectively v_{a2}, v_2, I_2, N_2, and so on. The structure of motion model of hybrid manipulator is shown as follows (Fig. 1).

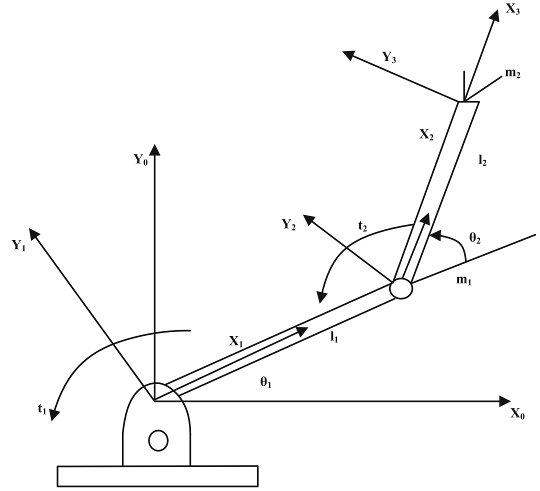

Fig. 1. Structure of motion model of hybrid manipulator

2.2 Dynamic Analysis of Hybrid Manipulator

Provided that the hybrid manipulator has i levels, the length of hybrid manipulator is l_i, the maximum head angle of is θ_i, the mass of manipulator is m_i, with unit distance, the mass of manipulator m_i/l_i. The acceleration of mass center of manipulator is v_{ai}, uniform motion speed is v_i, inertia tensor is I_i, effort torque is N_i. Based on newton-andrews law, the motion vectors of hybrid manipulator are analyzed. Based on Newton's first law of motion, the manipulator is stressed by downward gravity and upward braced force, with the influence of motor kinetic energy, the manipulator moves. It's assuming that motor kinetic energy provides E energy, and the mechanical connection consumes E_1 energy, the resistance to motion consumes E_2 energy, then $E_1+E_2 \ll E$, the mass that manipulator graspes is variable, there is certain uncertainty in path, provided that the grasping mass is m_x, the balance equation of dynamic vector is given by [4]:

$$m_i I_i N_i = \frac{{}_{i}^{i+1}\sin v_i \theta_i^2}{(E - E_1 - E_2) l_i} \tag{1}$$

Provided that the variation period of mechanical motion vector is *f*, an upward moment of force is generated by the motion of manipulator form first-level to upper level, on the key joint, with the influence of inertia force I_i, when the manipulator graspes the object whose mass is m_x, the origin of hybrid manipulator keeps O, dynamic equilibrium is formed and meets the rules of following equation:

$$m_x I_i N_i = \cos v_i \theta_i^2 f / l_i (E - E_1 - E_2) \tag{2}$$

From above equation, it can be concluded that:

If $\mathrm{E_S} > \mathrm{E_R}$, the hybrid manipulator presents the trend of upward motion, meanwhile, the inertia tensor value I_i is positive.
If $\mathrm{E_S} < \mathrm{E_R}$, the hybrid manipulator presents the trend of downward motion, meanwhile, the inertia tensor value I_i is negative.
If $\mathrm{E_S} = \mathrm{E_R}$, the hybrid manipulator keeps motionless, meanwhile, the inertia tensor value I_i is zero.

Where $\mathrm{E_S}$ represents the equilibrant of dynamic vector, $\mathrm{E_R}$ the dynamic equilibrium of hybrid manipulator. Based on newton-andrews law, the motion trend of hybrid manipulator is analyzed and conclusions are obtained. The conclusion of motion vector trend of hybrid manipulator is combined with the time control unit to obtain the motion vector status of hybrid manipulator in unit time. According to the status of motion vector, the motion direction is identified, based on variations of force, the dynamic motion mathematical prediction matrix of hybrid manipulator is built [5, 6], of which the equation is as follows:

$$D = |M(q)| = \begin{bmatrix} 0 \\ m_x f \\ 0 \\ I_i \end{bmatrix}, F = |G(q)| = \begin{bmatrix} E_S \\ 0 \\ E_R \\ I_i \end{bmatrix} \tag{3}$$

Where D represents the control variable program of hybrid manipulator, F the dynamic variable control function of hybrid manipulator, $\mathrm{E_S}$ the equilibrant of dynamic vector, and $\mathrm{E_R}$ the dynamic equilibrium of hybrid manipulator.

2.3 Dynamic Characteristics of Hybrid Manipulator

Based on the dynamic analysis of hybrid manipulator, following dynamic characteristics can be confirmed:

1. With the increasement of key joint of manipulator, the calculation intensity increases, and geometric linear uncertainty increases.

2. The dynamic range of the dynamic model of the hybrid manipulator is wider, it can be simulated by the PLC fuzzy control unit, meanwhile, it can ensure high coupling and reduce the influence of random interference and uncertainty.
3. The dynamic inertia matrix of hybrid manipulator meets q $\in$ R^n, $|M(q)| \leq$ d, and d is a constant.
4. M(q)-2C is matrix inverse, and

$$m_x I_i N_i - \cos v_i \theta_i^2 f \big/ l_i (E - E_1 - E_2) = 0 \quad \forall x \in R^n.$$

5. Gravity G(q) has threshold value for q $\in$ R^n, where $|G(q)| \leq d \leq a$, the integration of threshold value is constant.

3 Structure Design of Trajectory Prediction Algorithm

3.1 Construction of PLC Fuzzy Control Unit

The construction of PLC fuzzy control unit is the basis of hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control, likewise, the motion analysis of hybrid manipulator structure is the basis of construction of PLC fuzzy control unit. Through the analysis data of hybrid manipulator motion, the influence of hybrid dynamic inertia and gravity is determined. The parameters value is assigned according to confirmed influence parameters, and fuzzy controller is introduced, which mainly includes calculation of control variables, fuzzification, quantification of fuzzy control, fuzzy inference, defuzzification and D/A transfer [7] (Fig. 2).

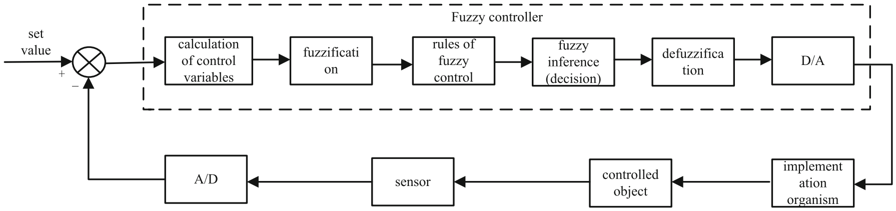

Fig. 2. Principle of fuzzy control

3.2 Confirme the Input and Output Variables of PLC Fuzzy Control Unit

The PLC fuzzy control unit is introduced according to the dynamic characteristics of hybrid manipulator, and kinematic analysis of the manipulator is performed. The control variable of PLC is the motion state of hybrid manipulator. When analyzing and predicting the fuzzy control, the control variable of PLC is converted from the motion state of hybrid manipulator to the definition threshold of fuzzy function, the input and output variable thresholds are compared and analyzed. The input variable thresholds include the inverse matrix constant of M(q)-2C, the motion compensation of the manipulator, and the dynamic inertia matrix of hybrid manipulator [8, 9]. Correspondingly, the output variable thresholds include the dynamic motion mathematical prediction matrix of hybrid manipulator and the variation period of mechanical motion vector.

3.3 Confirme the Parameters of PLC Fuzzy Control Unit

To confirme the parameters of PLC fuzzy control unit, it's necessary to confirme the input and output variable thresholds of fuzzy control unit, but dimension nonuniformity exists in inverse matrix constant of M(q)-2C and dynamic motion mathematical prediction matrix of hybrid manipulator, dimensionless processing for input and output variables is needed to confirme the domain and parameters of the input and output variables of PLC fuzzy control unit. With the calculation method of fuzzy control, the domain and parameters are determined rapidly by curve-parameter method, the domain curves of input and output variables are shown as follows [10] (Fig. 3).

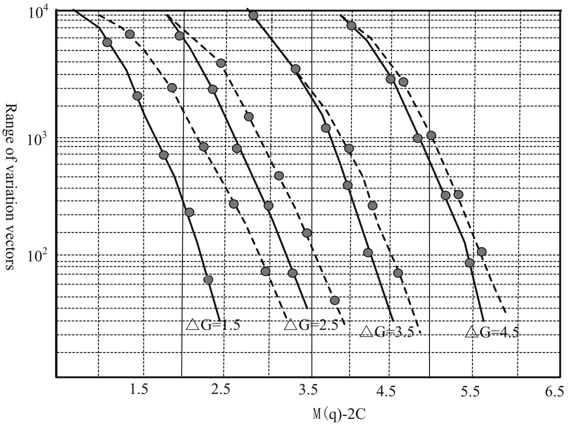

Fig. 3. Domain curves of input and output variables

3.4 Defuzzification Strategy and Analysis

The domain and parameters of the input and output variables are smaller than 2.5, the curve with lower ΔG value is selected to be substituted into fuzzy control unit, the trajectory prediction calculation is performed.

The domain and parameters of the input and output variables are smaller than 5.0 and larger than 2.5, the curve with higher ΔG value is selected to be substituted into fuzzy control unit, the trajectory prediction calculation is performed.

The domain and parameters of the input and output variables are larger than 5.0, the curve with mean ΔG value is selected to be substituted into fuzzy control unit, the trajectory prediction calculation is performed.

4 System Test and Analysis

To ensure the effectiveness of the proposed algorithm based on PLC fuzzy control for hybrid manipulators' trajectory prediction, system testing and analysis are carried out. In the testing process, different manipulators were used as test objects to perform the trajectory prediction analysis test of hybrid manipulators. Different key joints and structures of the manipulator are simulated. To ensure the validity of the test, the conventional manipulator trajectory prediction algorithm is used as a comparison object, and the results of the two simulation tests are compared. The test data was presented on the same data chart and the test conclusions are analyzed.

4.1 Preparation of System Test

To ensure the accuracy of the simulation test process, the test parameters are set. This paper simulates the test process, uses different manipulators as the test objects, uses two different manipulators' trajectory prediction algorithms, performs the hybrid manipulator's trajectory prediction analysis test, and analyzes the simulation test results. Because the analysis results and analysis methods obtained in different methods are different, therefore, the test environment parameters must be consistent during the testing process. The test data setting results in this paper are shown in Table 1.

Table 1. Test parameters

Item	Model	Range/parameters
Dynamic parameters of hybrid manipulator	Mitshubishi L5-14	300 kJ/h
Set the complexity of variable manipulator	∞ mechanical joint* mechanical freedom	0–80%
Analysis of error-tolerant rate of error	–	<0.05%

4.2 Test of Trajectory Prediction

During the test, two different manipulators' trajectory prediction algorithms were compared with the exact values of the simulation to analyze the changes in the manipulator's trajectory. At the same time, due to the use of two different manipulator trajectory prediction algorithms, the analysis results cannot be compared directly. For this purpose, third-party analysis and recording software is used to record and analyze the testing process and results, and the results are displayed in the comparison curve of results of this test. The test result comparison curve is shown in Fig. 4. Based on the third-party analysis and recording software, it can be concluded that the proposed prediction algorithm improves the accuracy of rapid analysis by 57.42% compared with the conventional prediction algorithm, and is suitable for the prediction of the trajectory of the hybrid manipulator.

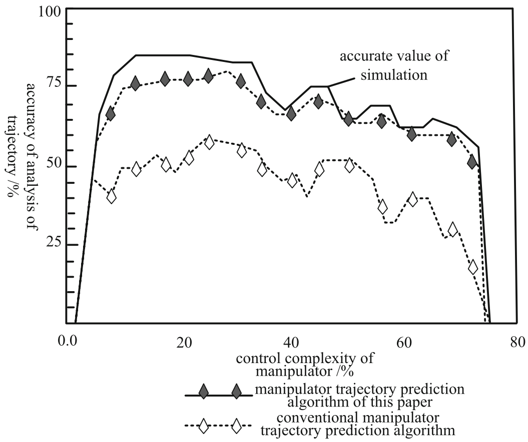

Fig. 4. Test result comparison curve

5 Conclusion

Hybrid manipulator running trajectory prediction algorithm based on PLC fuzzy control is proposed in this paper, based on motion analysis of hybrid manipulator structure, the dynamic model of hybrid manipulator is constructed to determine the dynamic characteristics of hybrid manipulator. Based on PLC fuzzy control unit, and the determination of domain and parameters of input and output variables, defuzzification strategy and analysis are performed. Test data show that the method designed in this paper is quite effective. The paper is written with the desire that the research will provide theoretical basis for trajectory prediction algorithm of manipulator.

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