Research on an Algorithm of Six Degrees of Freedom Manipulator Arm Moving with End Trajectory

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Abstract. Under manipulator trajectory motion algorithm, the time consumption of manipulator motion is long, and the stability coefficient is low, and the accuracy of obstacle avoidance is poor. An algorithm that six degree of freedom manipulator moves with end trajectory based on particle swarm optimization was proposed. By analyzing the positive solution of kinematics and inverse solution of kinematics of manipulator, the expected pose of manipulator was obtained to realize the analysis of manipulator trajectory. According to the constraint condition of the short time consumption of motion, the high accuracy of obstacle avoidance and the strong motion stability, the model that six degree of freedom manipulator ARM moved with end trajectory is built. The model was subdivided into particle swarm optimization algorithm to realize the solution of model. Then, some parameters such as initial position and speed of particle swarm were set, and particle swarm fitness function was calculated to get the optimal solution. Finally, we determined whether the current optimal solution was the global optimal solution. Thus, we obtained the optimal planning results that the manipulator moves with the end trajectory. Experiment shows that the time consumption of manipulator motion is short. The average accuracy of obstacle avoidance is 95%. The stability coefficient is high. This algorithm can effectively solve the problem of current algorithm, which has practicality.

Keywords: Six degrees of freedom · Manipulator arm · End trajectory motion · Particle swarm

1 Introduction

With the continuous development of mechanization, the form of robot becomes more advanced. Currently, the mechanical arm is widely used. There is still a large gap between China and foreign countries in developing and using mechanical arms. To research the whole operation of mechanical ARM is a very effective way. The trajectory tracking control of mechanical ARM is an important part of development of robot technology, which has high research value [1]. Due to the high research value of mechanical arm, many experts and scholars begin to analyze and study them in succession. Therefore, there have been some excellent research results.

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Reference [2] proposes a method for planning movement track of manipulator based on Cartesian space. The D-H matrix is used to realize the mathematical modeling of position and pose of manipulator. Then, circular interpolation method in Cartesian space is used to complete the path planning and obtain the smooth movement track. Finally, the artificial potential field is used to make the manipulator arm reach the termini without obstacle. Experiment proves that the proposed algorithm improves the accuracy of obstacle avoidance of manipulator, but it has a long time-consuming problem. Reference [3] proposes that the structural characteristic of picking manipulator is used to realize the modeling of structure parameters of mechanical arm through Denavit-Hartenberg and obtain the positive kinematics model. In solving inverse kinematics, the inverse kinematics equation is used to change the complex matrix into the easy algebraic equation, so as to complete the analysis of inverse kinematics. Thus, the optimal inverse solution is calculated based on the minimum energy principle. Experimental results show that the motion of manipulator arm is relatively stable with this algorithm, but the accuracy is poor in avoiding obstacles. Reference [4] proposes a robot trajectory method based on inverse solution of kinematics. On the basis of coordinated hoisting and transporting of multi robots for the same object structure, the kinematics model of coordinated operation system is built. The analytic formula of inverse kinematics of coordinated operation system is analyzed. Meanwhile, the analytic formula of inverse kinematics is given. The experimental platform is constructed through UG/ ADAMS/ MATLAB simulation system. Experiment shows that the operation process of this method is relatively simple, but the multi-robots coordination system cannot avoid the obstacle accurately by using this method. In reference [5], a tracking motion algorithm of manipulator arm based on predictive control is proposed. The analytical mechanics material is used to infer the difficulty formula under the load of mechanical arm, so as to obtain the kinematics model of manipulator system. On the basis of above, the simplified processing of kinematic model of manipulator system is realized, such as reduced order and linearization. The motion priority level is determined through the range of motion of each joint in model and the accuracy of positioning. Meanwhile, the real-time updates and the rolling optimization are used to ensure the timeliness of control. Experimental results show that this algorithm solves the motion redundancy, but the motion stability of manipulator ARM is poor.

At present, some related algorithms about the manipulator trajectory motion cannot realize the goal of high accuracy, high stability and low delay. Therefore, this article proposes an algorithm that six degrees of freedom manipulator tracks with the end trajectory based on particle swarm. The main structure is:

(1) According to the positive solution of kinematics and inverse solution of kinematics, we analyze that the six degrees of freedom manipulator tracks with the end trajectory, and build the model.
(2) Use particle swarm optimization algorithm to solve the model that six degrees of freedom manipulator tracks with the end trajectory, get the best planning way of manipulator arm to track the end trajectory.
(3) The feasibility of proposed algorithm is proved by the experiment.
(4) Summarize the full text and give the future research direction.

2 Algorithm of Six Degrees of Freedom Manipulator Arm for Following End Track

2.1 The Establishment of Trajectory Model and the Analysis of End Trajectory Motion of Manipulator Arm

To analyze that six degree of freedom manipulator moves with the end trajectory and build the trajectory kinematic model needs to construct the coordinate system of manipulator arm. Figure 1 is the coordinate system of manipulator arm.In Fig. 1, there are six joints in the six degree of freedom manipulator structure. For the purpose of describing the position and posture of end effect or of manipulator arm in space, a coordinate system is built on each joint. Thus, the position of end effect or is described through the relationship between coordinate systems.

(1). Positive solution of kinematics. The process of positive solution of kinematics of manipulator arm is the process using rotation angle of known joint variables θ_1, θ_2, θ_3, θ_4, θ_5 and θ_6 to get the pose of end gripper relative to reference coordinate system. The reference coordinate system is set on the base of six degree of freedom manipulator arm by the D-H method of standard upper joint [6]. It begins to change from base to the first joint, then to the second joint, and so on. Finally, it changes to the end gripper.

(2). Inverse solution of kinematics. The process of solving inverse solution of kinematics is the process of using pose of known end gripper relative to the reference coordinate system to get joint variable θ_1, θ_2, θ_3, θ_4, θ_5 and θ_6. It is the basis of the trajectory planning and trajectory control. It is also the most important part of kinematics [7]. According to the content above, the formula of the expected pose of manipulator arm is given.

$$TH = \begin{pmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

Where, n denotes normal. o denotes the direction. a denotes the approaching vector. p denotes the origin of coordinate system of manipulator end gripper. Corresponding to the position vector of base coordinate system, x, y and z denote three coordinate directions of coordinate system. Generally, p can be given by using the position of work piece. n, o and o can be given by using rotation of rolling angle, pitching angle, and drift angle [8].

For the purpose of convenient calculation, we combine the joint 1 and joint 2 with the joint 5 and joint 6. Thus, the total transformation between the base and the hand of the six degree of freedom manipulator can be expressed as formula (1). According to the requirement of desired position in formula (1), manipulator may have multiple combinations of joint rotation in the same posture, so we must choose the optimal solution based on the actual structure of manipulator arm. In order to achieve the purpose of short time consumption, high accuracy of obstacle avoidance and strong

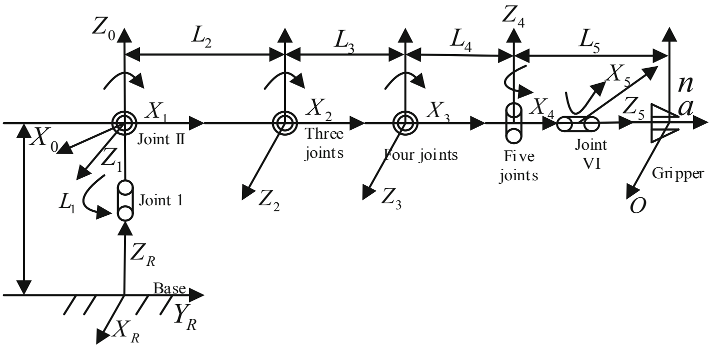


Fig. 1. Coordinate system of six degrees of freedom manipulator arm

motion stability, we take the three points as constraint conditions to build the model that a six degree of freedom manipulator moves with end trajectory.

According to the above content and the position of terminal actuator described by the six degree of freedom manipulator coordinate system, the positive solution of kinematics and inverse solution of kinematics are analyzed. The desired posture of manipulator ARM is calculated. According to the constraint condition of the short time consumption of manipulator motion, the high accuracy of obstacle avoidance and the strong motion stability, the objective function of model that six degree of freedom manipulator ARM moves with end trajectory is built.

2.2 To Solve Trajectory Model of Manipulator Arm Based on Particle Swarm

The particle swarm optimization algorithm is used to solve the model established in Sect. 2.1. The detailed process is as follows:

To randomly generate M particles to construct the initial particle swarm, and set the initial position and initial speed of particle, the fitness function is calculated according to parameters [9]. Supposing that any function of three objective functions in the model established by Sect. 2.1 is not consistent with the formula (3), then the fitness function of particle swarm can be expressed as $|U(J,I)|$, and the particle swarm optimization algorithm will decrease $|U(J,I)|$ in the process of loop iteration until it meets the constraint condition.

$$f(U) = \sum M \times |U(J,I)| \times A_{JI} \tag{2}$$

Where, $f(U)$ denotes the constraint function of all joint motion in the six degree of freedom manipulator arm.A_{JI} denotes the influence coefficient selected by the fitness function of particle swarm. J denotes J th group in M groups of populations, and I denotes the number of populations which are not satisfied formula (2). Supposing that the three objective functions in model built by Sect. 2.1 are all conform to the formula (2), the fitness function can be expressed as $-|U(J,I)|$.

The optimal value after the *k*-th iteration and the optimal value of groups are selected by using the fitness function. The population is reintegrated and new particle swarm is formed. The formula of current optimal value is as follows:

$$Best(U) = \frac{f(U) \times (J, I) \times A_{JI}}{\sqrt{TH} \times k} \tag{3}$$

The calculation from formula (3) is used to determine whether the current optimal solution is the global optimal. If it isthe global optimal, the optimization stops. If it is not, the iteration will continue until it meets the iteration stop condition, and then the optimal value will be output. The optimal solution obtained by using formula (3) is the optimal planning result that the six degree of freedom manipulator arm moving with the end trajectory [10, 11].

In conclusion, the particle swarm optimization algorithm is used to solve the model that six degree of freedom manipulator arm moves with the end trajectory. The parameters of particle swarm location and initial speed are set, and the fitness function of particle swarm is determined [12, 13]. To calculate current optimal solution and judge whether this solution is the global optimal solution can obtain optimal solution which satisfies short time consumption of mechanical arm movement, high accuracy of obstacle avoidance and strong stability of motion [14, 15]. Thus, the planning research that six degrees of freedom manipulator arm moves with end track can be completed.

3 Experimental Results and Analysis

In order to prove the feasibility of algorithm for tracking the end trajectory of six degree of freedom manipulator based on particle swarm optimization, the experimental platform was built on VC++6.0, and the object was shown in Fig. 2. The simulation time was 0–60 s. Experimental indexes were set up in three aspects: the time consumption of manipulator arm motion, the accuracy of avoiding obstacle and the stability of motion.

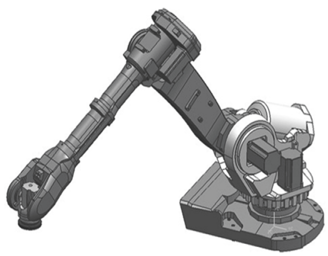


Fig. 2. Experimental objects

Different algorithms were applied to experimental objects, and the effectiveness of proposed algorithm was verified by three indexes above. Experimental results were as follows:

3.1 Experiment (First) Results

According to the analysis of experimental result in Fig. 3, under the same number of work pieces, the time consumption of manipulator arm in manipulator ARM motion track planning algorithm based on Cartesian space was long, and the time-consuming curve fluctuates greatly. The time consumption of manipulator arm based on particle swarm was relatively short and the time-consuming curve was relatively stable. When the number of work pieces was 30, obviously, the time consumption of manipulator ARM motion track algorithm based on particle swarm optimization was15s less than time consumption of manipulator ARM motion track planning algorithm based on Cartesian space. The experimental data show that the proposed algorithm has absolute superiority.

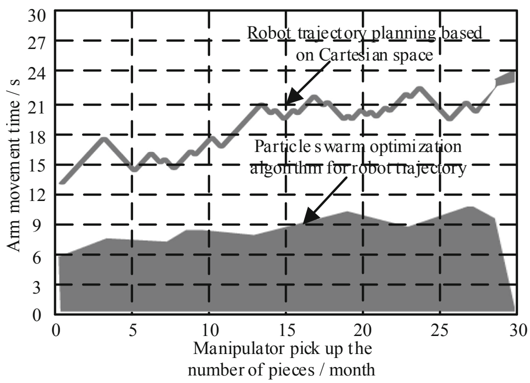


Fig. 3. Comparison of time consumption of manipulator arm motion with different algorithms

3.2 Experiment (Second) Results

From Fig. 4, we can see that the accuracy curve of obstacle avoidance of trajectory motion algorithm for manipulator arm based on Denavit-Hartenberg was first increased and then decreased, and the average accuracy of obstacle avoidance is about 50%. Thus, the reliability is low. In the preliminary stage of avoiding obstacles, the accuracy curve of robotic trajectory method based on inverse kinematics showed a steady rising trend. However, with the increase of obstacles, the accuracy curve of obstacle avoidance decreased faster, and the average accuracy of obstacle avoidance was about 45%. The accuracy curve of obstacle avoidance using algorithm of mechanical arm trajectory based on particle swarm optimization had shown a trend of stable increase, and tended to slow at about 97%, and the average obstacle avoidance accuracy was 95%. This data proves that the proposed algorithm was superior to the current algorithm in the accuracy of obstacle avoidance.

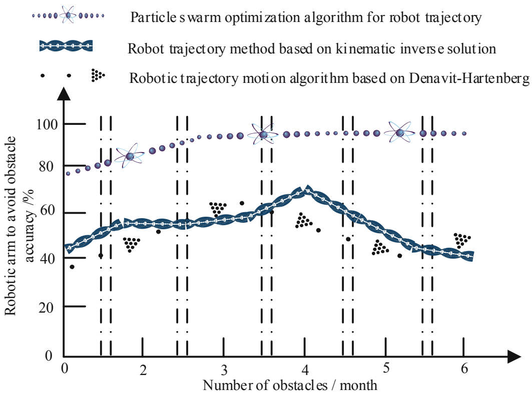
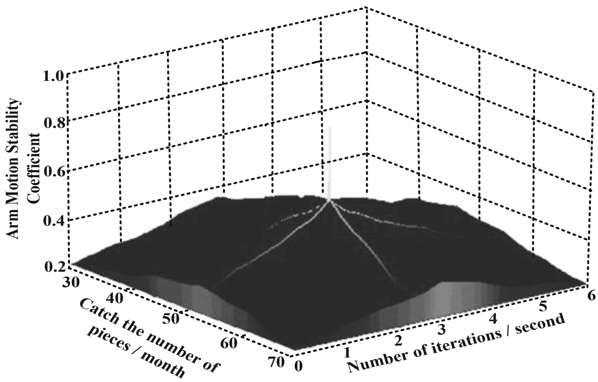


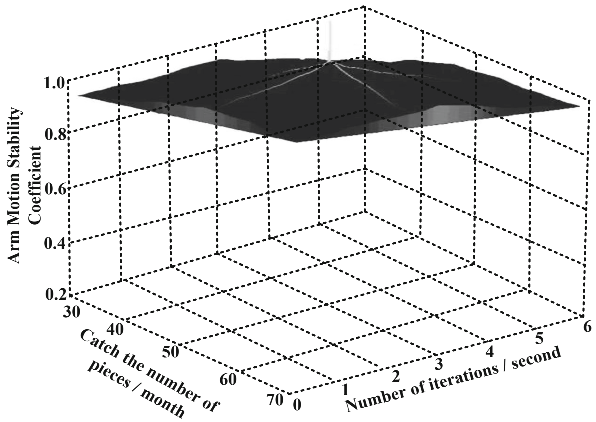
Fig. 4. Comparison of accuracy of obstacle avoidance with different algorithms

3.3 Experiment (Third) Results

According to the analysis of the experimental results in Fig. 5, the stability of the manipulator arm based on predictive control is poor. The maximum stability coefficient is 0.58. The feasibility is very low. In the trajectory motion algorithm of manipulator based on particle swarm optimization algorithm, the motion stability of manipulator arm is strong. The maximum value is 0.98. Compared with the existing algorithms, this algorithm has better motion stability. This algorithm is superior to the existing algorithms in the aspects of time consumption, obstacle avoidance accuracy and motion stability of the manipulator.



(a) Coefficients ofmotion stability of manipulator armin manipulator arm trajectory motion algorithmbased on predictive control



(b) Coefficient of motion stability of mechanical arm based on particle swarm optimization in manipulator track motion algorithm

Fig. 5. Comparison of motion stability of manipulator arm with different algorithms

4 Conclusions

With the constant innovation of modern technology, the current manipulator trajectory tracking algorithm is unable to satisfy the development needs of this field. An algorithm for tracking the end trajectory of six degree of freedom manipulator based on particle swarm was proposed. The inverse kinematic solution and positive kinematic solution of manipulator arm were analyzed. The motion time consumption of manipulator ARM and the accuracy and stability of obstacle avoidance were taken as constraint conditions. Then, the trajectory motion model of manipulator arm was built.

Finally, the particle swarm optimization algorithm was used to solve the model. Thus, the best planning result of manipulator arm was obtained. Experimental results show that the proposed algorithm is superior to the current algorithm in the motion time consumption of manipulator arm, the accuracy of obstacle avoidance and the stability of motion. For the development direction in the future, the following suggestions are presented:

(1) The manipulator arm is mostly applied to the industrial field. But, different trajectory planning algorithms should be used for different types of manipulator ARMs, so as to get better application results.
(2) In this research, the cost problem of trajectory planning is not considered, and it is necessary to consider this kind of problem in the future research.

References

1. Granatosky, M.C., Schmitt, D.: The mechanical origins of arm-swinging. J. Human Evol. **130**(6), 61–71 (2019)
2. Fu, Q., Wang, Z.: An obstacle avoidance trajectory planning for double manipulators. Electronic Design Eng. **25**(16), 68–72 (2017)
3. Teng, J.Y., Xu, H.B., Wang, Y., et al.: Design and simulation of motion trajectory planning for manipulator of picking robot. Comput. Simul. **34**(4), 362–367 (2017)
4. Ishikawa, A., Sakai, T., Fujii, K.: An ionic liquid gel with ultralow concentrations of tetra-arm polymers: Gelation kinetics and mechanical and ion-conducting properties. Polymer **166** (12), 38–43 (2019)
5. Levenhagen, N.P., Dadmun, M.D.: Reactive processing in extrusion-based 3d printing to improve isotropy and mechanical properties. Macromolecules **52**(17), 15–21 (2019)
6. Pekarovskiy, A., Nierhoff, T., Hirche, S., et al.: Dynamically consistent online adaptation of fast motions for robotic manipulators. IEEE Trans. Robot. **12**(99), 1–17 (2017)
7. Tiller, N.B., Campbell, I.G., Romer, L.M.: Mechanical-ventilatory responses to peak and ventilation-matched upper- versus lower-body exercise in normal subjects. Exper. Physiol. **104**(15), 25–31 (2019)
8. Garcia, A.N., Lucíola da, C., Menezes, C., Hancock, M.J, et al.: McKenzie method of mechanical diagnosis and therapy was slightly more effective than placebo for pain, but not for disability, in patients with chronic non-specific low back pain: a randomised placebo controlled trial with short and longer term follow-up. British J. Sports Med. **52(**9), 594–599 (2018)
9. Asl, H.J., Yoon, J.: Robust trajectory tracking control of cable-driven parallel robots. Nonlinear Dyn. **89**(4), 2769–2784 (2017)
10. Park, J., Karumanchi, S., Iagnemma, K.: Homotopy-based divide-and-conquer strategy for optimal trajectory planning via mixed-integer programming. IEEE Trans. Robot. **31**(5), 1101–1115 (2017)
11. Bulvas, M., Zuzana, S., Ivan, V., et al.: Prospective single-arm trial of endovascular mechanical debulking as initial therapy in patients with acute and subacute lower limb ischemia: one-year outcomes. J. Endovascular Therapy, **26**(3), 152–160 (2019)
12. Liu, S., Liu, D., Srivastava, G., et al.: Overview and methods of correlation filter algorithms in object tracking. Complex Intell. Syst. (2020) 10.1007/s40747-020-00161-4

13. Shuai, L., Gelan, Y.: Advanced hybrid information processing. Springer International Publishing, USA (2019)
14. Liu, S., Lu, M., Li, H., et al.: Prediction of gene expression patterns with generalized linear regression model. Front. Genet. **10**, 120 (2019)
15. Lu, M., Liu, S.: Nucleosome positioning based on generalized relative entropy. Soft. Comput. **23**(19), 9175–9188 (2018). https://doi.org/10.1007/s00500-018-3602-2