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Simulation of Robot Manipulator Trajectory Optimization Design

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***ABSTRACT**: Most of the trajectory planning based on robot dynamics and kinematics start from the joint space, can not guarantee the robot end track corresponding relationship. To solve the above problem, the method of trajectory planning is proposed and the optimization algorithm is used to solve the optimization trajectory. Taking the SCARA robot as an example, the trajectory of the end trajectory is preset, the first trajectory is planned by combining the first order acceleration planning and the arc transition. Then, the target model is optimized for the average power and the movement time. Finally, a non-dominated sorting algorithm is introduced to optimize the trajectory to obtain the best performance trajectory. The simulation results show that the optimized trajectory has a certain amount of time-consuming increase compared with the traditional trajectory of SCARA robot, but its energy consumption is obviously reduced, and the overall optimization result is obvious.*
***Keywords**: SCARA robot; NSDE algorithm; trajectory optimization;*

I. INTERODUCTION

The robot trajectory has a significant effect on the robot's energy consumption, life expectancy and its working efficiency. For the robot trajectory optimization problem, domestic and foreign scholars have a lot of research. Gong Li used the genetic algorithm to improve the length of the manipulator [1], so that the dynamic performance of the robot was improved, but the method was too complicated and the use was very difficult. Wang Huifang used the B-spline to simulate the joint trajectory of the joint space [2] Dominate the sorting genetic algorithm to optimize the energy of the joint space and the impact of the joint. However, using the B-spline interpolation point, the larger the interpolation order, the larger the interpolation point and the interpolation order will lead to discontinuous, Wang Xin used the third-order polynomial to simulate the motion trajectory of the joint space [3] and used the classical genetic algorithm to optimize the time and energy of the joint motion, but the traditional genetic algorithm solution set was not enough To ensure that the end trajectory can correspond to the planning trajectory.

Therefore, in order to ensure the exact correspondence between the joint trajectory and the trajectory, the simplification of the algorithm and the diversity of the solution set are optimized. The end trajectory planning is proposed, and the trajectory planning is carried out directly. Then, the optimization of the robot performance is optimized. So the difficulty of the optimization of the end trajectory is mainly the planning of the trajectory and the establishment of the corresponding optimization model.

II. PRINCIPLE OF THE END TRAJECTORY OPTIMIZATION

This article is mainly for energy and time-consuming two aspects of optimization. In the traditional joint space trajectory planning, the energy consumption is usually solved directly by the velocity and acceleration of the joints, and then the kinetic model is used to solve the energy consumption. In this paper, a trajectory of the end is preliminarily set for the problem of terminal trajectory optimization. Then, the velocity and acceleration are programmed. The velocity, acceleration and kinetic model of the joint are calculated by the inverse kinematics of the robot. Finally, we use the optimization algorithm to find the optimal trajectory of various performance indexes on the basis of the preset end trajectory.

2.1 End trajectory setting

SCARA used in industrial production is very extensive, the work process is simple and fast that the target caught, the last shift placed in the target point, Figure 1 is in the matlab environment using robotics toolbox simulation out of the SCARA model The The robot has four joints (cylinder in the figure) q1, q2, q3, q4, and the connecting rods l1, l2, d3 (straight lines in the figure). In this paper, we mainly study the trajectory of the process of the process of translating the object, that is, the arc trajectory in the graph, and plan and optimize it.

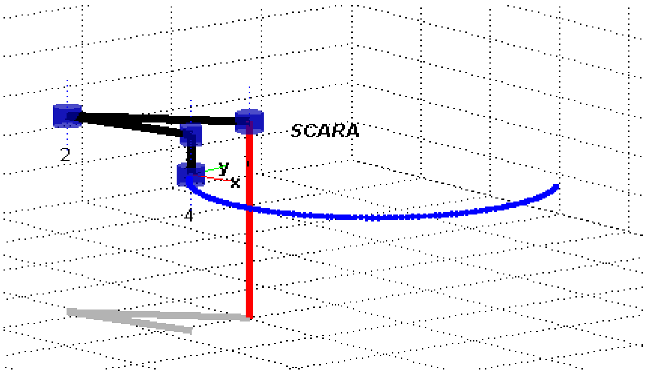


Fig1 Robot modeling model in matlab environment

In order to set an end trajectory before optimization, this paper chooses the starting point of the end of the robot and any point in its movement space as the key point. Figure 2, P_S, P_E, P_C for a given key simulation scara robot end trajectory preset track.

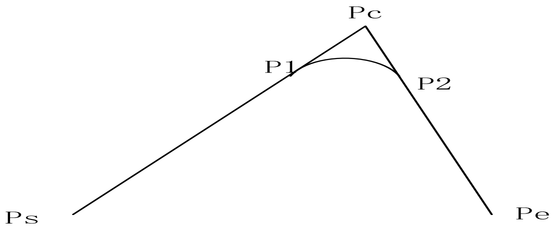


Fig2 Preset end trajectory

P_S is the starting point of the end, Pe is the end point of the end, and Pc is one of the end motions. Observation of the figure we can see, when the end of the track directly through the P_C point will be guidedInduced acceleration mutation. Therefore, the need for P_C point to do arc transition processing. The original from P_1P_C to P_CP_2 path through the arc P_1P_2 transition [5], to ensure that the end of the movement of the joint movement of the smooth.

2.2 Scheduled Track Speed Planning

For the speed of a given trajectory, the acceleration of the planning method is generally sinusoidal acceleration planning, exponential acceleration planning, acceleration planning [4], this paper selected in line with the actual situation of this acceleration method on the end of the Cartesian space Speed planning. Theacceleration method, that is, the first-order linear programming of the acceleration, equation(1) is the acceleration planning, for the completion of the planning trajectory, its speed, displacement can be obtained by integrating the acceleration.

$$a(t)=\begin{cases} 6\times a_{\max}\times\dfrac{t}{T} & (0\le t\le\dfrac{T}{6}) \\ a_{\max} & (\dfrac{T}{6}\le t\le\dfrac{T}{3}) \\ -\dfrac{6\times a_{\max}}{T}\times(t-\dfrac{T}{2}) & (\dfrac{T}{3}\le t\le\dfrac{2T}{3}) \\ -a_{\max} & (\dfrac{2T}{3}\le t\le\dfrac{5T}{6}) \\ \dfrac{6\times a_{\max}}{T}\times(t-T) & (\dfrac{5T}{6}\le t\le T) \end{cases} \quad (1)$$

According to equation (1), the straight line segment P_sP_c and P_cP_e movement process for the acceleration, uniform and deceleration, in accordance with the principle of first-order speed planning for the entire route segment planning, in order to make the transition process of circular speed, acceleration curve smooth, The point where the acceleration is 0 is the point of P_1, P_2, or the arc transition point, the length of the arc P_1P_2 can be determined.

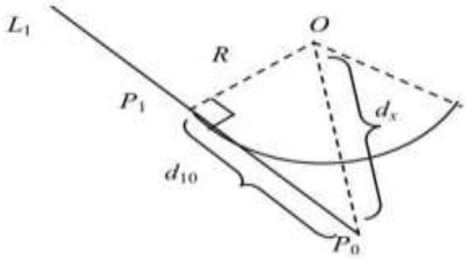


Fig3 Arc transition graph

When the P1 (X1, Y1), P2 (X2, Y2) is known, the length of the transition center O (a, b) and the transition circle radius R and the transition arc P_1P_2 can be determined according to the above figure 3 and equation(2) .The entire end path can thus be determined.

$$\begin{cases}(x1-a)^2+(y1-b)^2=R^2;\\(x2-a)^2+(y2-b)^2=R^2;\\R^2+d_{10}^2=d_x^2.\end{cases}\quad(2)$$

The motion trajectory of the manipulator consists of straight segments P_sP_1, P_2P_e and arc P_1P_2. According to equations (1) andequations (2), the trajectory of the end of the manipulator and the end velocity velocity Vs(t) and the acceleration a(t) corresponding to each time t can be determined.

2.3 Kinematics and dynamics analysis of SCARA robots

The velocity planning of the preset trajectory is determined, and its dynamic performance is analyzed. First, the results of its distal planning were switched to the joints. Secondly, the kinetic performance was analyzed by the joint dynamics model. In the first step, the speed and acceleration of the end plan are switched to the speed and speed of the joints. The inverse kinematics of the SCARA robot is analyzed. The instantaneous velocity, instantaneous acceleration and position instantaneous velocity($\dot{q}(t)$) Acceleration acceleration ($\ddot{q}(t)$) and position ($q(t)$). The second step, the dynamic analysis of SCARA robot. In this paper, the Lagrangian dynamics model is used to analyze the dynamic characteristics of the target.

Lagrangian dynamics equation is explicit:

$$M=D(q(t))\ddot{q}(t)+H(q(t),\ddot{q}(t))+G(q(t))\quad(3)$$

Where M is the vector of the joint drive torque. (D) is the inertial matrix of the system; through analysis, we can get the dynamic equation of SCARA robot:

$$\begin{cases}\tau_1=D_{11}\ddot{q}_1+D_{12}\ddot{q}_2+D_{14}\ddot{q}_4+2D_{112}\dot{q}_1\dot{q}_2+D_{122}\dot{q}_2^2\\\tau_2=D_{21}\ddot{q}_2+D_{22}\ddot{q}_2+D_{24}\ddot{q}_3+D_{211}\dot{q}_1^2\\\tau_3=D_{33}\ddot{q}_3-(m_3+m_4)g\\\tau_4=D_{41}\ddot{q}_1+D_{42}\ddot{q}_2+D_{44}\ddot{q}_4\end{cases}\quad(4)$$

Respectively, for the SCARA robot joints of the instantaneous moment, the main study:

III. OPTIMIZATION MODEL DESIGN

Through the analysis of the second section, Ps, Pe is the starting point of the determination, and Pc (x, y) is any point of the end trajectory, its position determines the end trajectory, and determines the energy consumption and movement time of the whole trajectory. For the time-consuming and energy-saving optimization of trajectories, it is necessary to establish a model of its relationship with Pc.

3.1 End trajectory optimization target

The instantaneous power P of each articulated motor during the movement of the manipulator can be expressed as the energy consumption of the manipulator. The instantaneous power P of the manipulator can be expressed as the product of the instantaneous angular velocity ($\dot{q}$) of the joint motor and the instantaneous torque. There are:

$$P = \sum_{i=1}^{4} p_i ; \qquad (5)$$

Where the instantaneous moment torque for the joint i is the instantaneous angular velocity of the joint i .The movement time of the manipulator is denoted by T.

$$T = \sum_{i=1}^{3} t_i ; \qquad (6)$$

As shown in Fig. 2, where t_1 denotes the time at which the mid end is at P_SP_1, t_2 denotes the time at which the terminal is at P_1P_2, and t_3 denotes the time at which the end is consumed in the P_2P_e segment.

From the analysis of the second section, it can be seen that the time of the trajectory movement and the instantaneous moment of the joint depend on the position of the P_c point. The average instantaneous power and exercise time as an objective function of optimization, in summary, the optimization objective function is as follows:

$$Min(P(Pc(x,y)),T(Pc(x,y))) \qquad (7)$$

among them:

$$\begin{cases} P = \sum_{i=1}^{4} p_i ,(p_i = \tau_i * v); \\ T = \sum_{i=1}^{3} t_1 ; \qquad ; \end{cases}$$

3.2 Constraints

The actual parameters of the robot are shown in Table 1.

Name	Quality(Kg)	Length(mm)
Base	13.2313	300
Upper arm	7.4884	325
Forearm	7.6037	275
Screw	0.7599	260

Table 1 SCARA robot's actual parameters

For the data of the SCARA joint motor, the selected joint motor is 400W Panasonic motor, the rated speed is 3000r / min, the maximum speed is 6000r / min, and the radian is about 314rad / sec - 628rad / sec. Machine is 1:50 of the transmission ratio, the actual wingspan speed range of the maximum range of 6.28rad / sec - 12.56rad / sec. 400w motor torque look-up table: the maximum range of 1.3 N * m - 3.8N * m, by the reducer torque amplification, the actual torque range should be 65N * m - 190N * m, according to the actual efficiency of about eighty percent Judge the maximum motor torque of the base motor and the arm in the range of 50N * m - 150 N * m.

The motion range of the SCARA robot joint 1 is [-5 * pi / 6,5 * pi / 6], the motion range of the joint 2 [-8 * pi / 9,8 * pi / 9], the movement of the end in the XY plane The range is also the range of motion of Pc (x, y) as shown in Fig4.

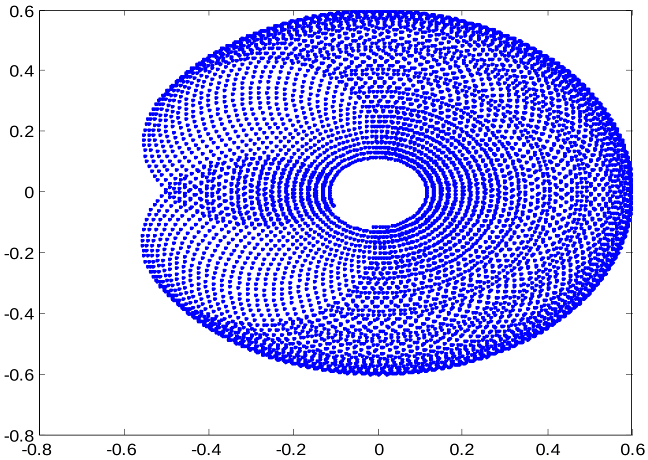


Fig4 The robot end is in the X-Y plane coordinate range of motion

In order to reduce the complexity of the search range and the complexity of the calculation, the range of Pc in the XY plane is chosen to be in the range of (0.2, 0.5) and y (0,0.45).

Constraints: In the range of motion on the XY plane of a given end, the joint torque and joint angular velocity of the SCARA robot joint motor must meet the following requirements:

$$\begin{cases} \tau_i < 150 \text{ N*m} & \text{(joint torque)} \\ \dot{q} < 12.56 \text{rad/s} & \text{(Joint angular velocity)} \\ a <= 20 \text{m/s}^2 & \text{(End acceleration)} \\ 0.2 <= x <= 0.5, 0 <= y <= 0.45 & \\ & \text{(Coordinate plane motion range)} \end{cases} \quad (8)$$

IV. NUMERICAL SIMULATION AND ANALYSIS

The non-dominated sorting genetic algorithm used by NSGA-II [6] (Non-Dominated Sorting Genetic Algorithm) and DE [7] (Differential Evolution) improved NSDE [8] (Non-Dominated Sorting Differential Evolution Algorith). First, NSGA-II non-domination and progeny individual selection mechanism; Second, the generation of sub-generation difference instead of the traditional NSGA-II analog binary cross and polynomial variants to generate progeny individual way. While maintaining the optimal solution of the diversity of the same time also simplifies the complexity of the algorithm [9]. According to the optimization target set, a set of Pareto optimal solution sets is obtained.

The concrete steps are as follows:

The first step is to initialize the population, randomly generate a population of scale N, set the algorithm maximum evolution algebra gmax, determine the crossover probability Pcc, mutation probability Pm; The second step: the use of DE algorithm for the initial population variation, crossover operator generation of offspring population Qt, the size of N; The third step is to combine the parental population Pt and the progeny population Qt to produce a population of 2N scale, and then carry out the non-dominant sorting and crowding distance operation of the population to obtain the new population Pt + 1 with the size N The fourth step: the new population of Pt + 1 for the tournament selection, the use of DE algorithm cross, mutation operator to generate new progeny population Qt + 1; Step 5: Determine whether the termination condition is reached or the evolutionary algebra is maximized. If the evolution is terminated, the optimal solution is output; otherwise, the third step is returned.

The maximum probability of evolution is Gmax = 30; the crossover probability Pcc = 0.5; the mutation probability Pm = 0.3; in the Cartesian coordinate system, the starting point of the end point is (0.2, 0.5) (Unit: m), the end point is (0.5,0.2). Run through Matlab to get the Pareto surface as shown in Figure 5.

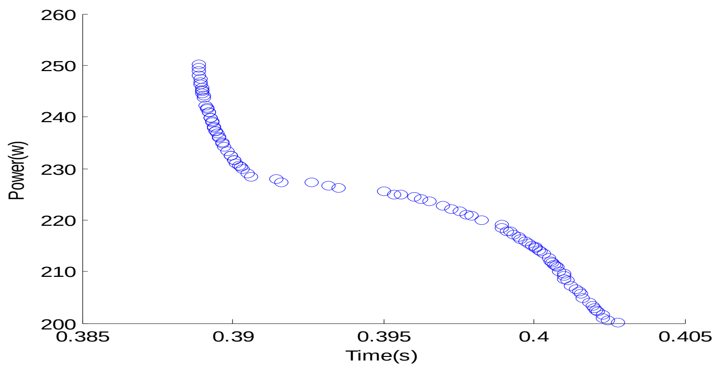


Fig5 Non-dominated solution set

The non-dominated solution of the Pareto frontier is analyzed and it is found that the acceleration of the joint is more stable when the Pc inflection point is close to the vertical line of Ps and Pe. The closer the Pc is to the Ps and Pe points, the less time is and the average power is larger The This is because the P1P2 transition arc connection is smoother when near the vertical line.

Number	Pc(x,y)	Time(s)	Power(W)
1	(0.2157, 0.4500)	0.3887	250.12
2	(0.3090, 0.3096)	0.4028	200.13
3	(0.3103, 0.3254)	0.4012	207.58
4	(0.3114, 0.3184)	0.4017	203.87
5	(0.2708, 0.3845)	0.3976	221.64

Table 2 Optional five sets of solutions for nonhomogeneous solutions

This article only selected one of the five solutions for analysis, see Table 2. The five solutions correspond to the five different paths formed by the different five positions of the Pc point under the constraint condition, and the five non-dominated solutions with different power consumption and power. Select the appropriate set of solutions from Table 2, let Pc be (0.3090,0.3096), the corresponding Pareto solution (0.4028,200.13), that is, time consuming T = 0.4028s, joint 1 and joint 2 average instantaneous power P = 200.13w, the trajectory at this time as shown in Figure 6.

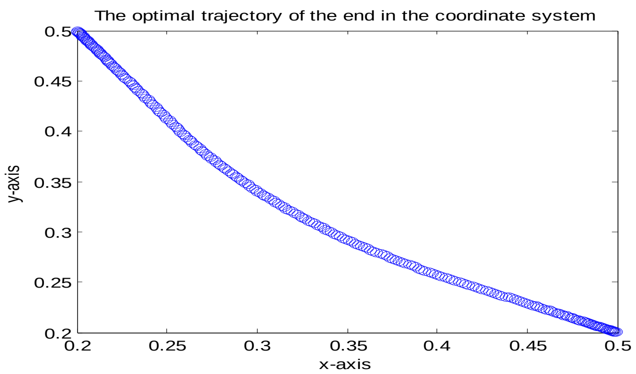
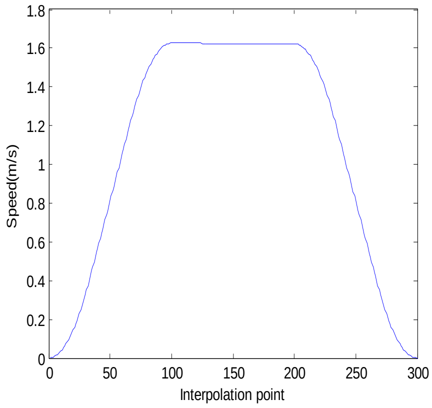


Fig6 Optimized trajectory of the trajectory

The kinematic and kinetic parameters can be obtained by numerical simulation. Figure 7, Figure 8, Figure 9 and Figure 10 show the optimized end velocity curve, joint angle change curve, joint velocity curve and joint torque curve.



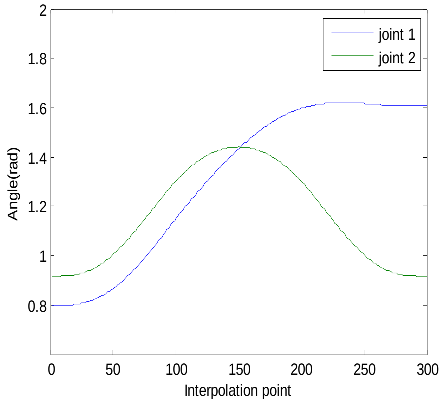
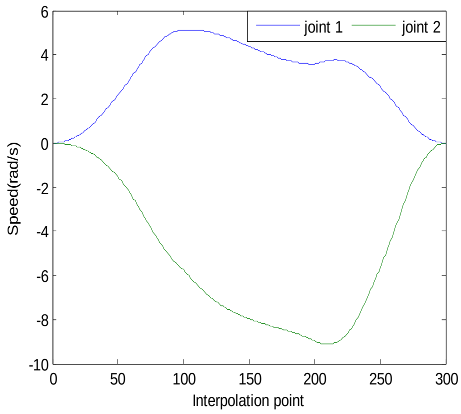


Fig7 End speed of first order acceleration planningFigure 8 Optimized joint angle change curve



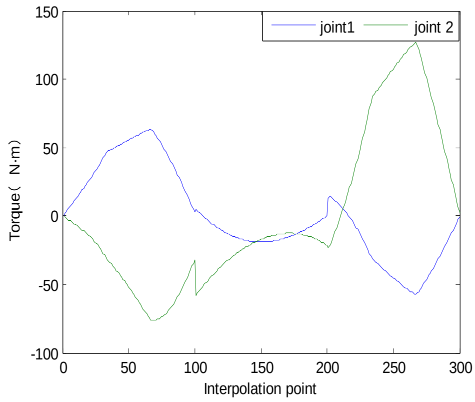


Fig 9 Optimized joint rotation speedFig 10 Variation of joint torque

When the trajectory of the SCARA robot moves along the standard trajectory, the time T = 0.3800s, the average instantaneous power P = 366.73w for the joints 1 and 2 is shown in Fig11.

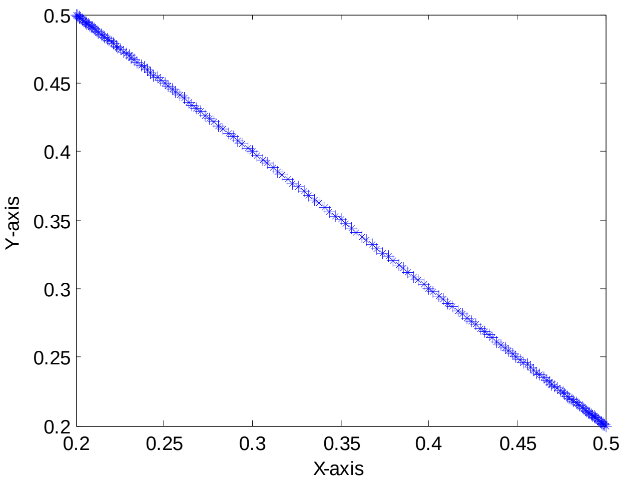


Fig11 The traditional trajectory of the SCARA end

The time-consuming and average instantaneous power before and after optimization are shown in Table 3.

	Time (s)	Average instantaneous power(w)	Energy consumption (w*s)
Before optimization	0.3800	366.73	139.375
After optimization	0.4027	200.09	80.576

Table 3 Optimize energy consumption before and after

Contrast optimization before and after trajectory Figure 6 and Figure 11. Optimized before the trajectory is a straight line, that is, the end of the SCARA raised the target, flat down. After the optimization of the trajectory is slightly concave, that is, the end of the SCARA lift the object, the process of translating the arm inward shrink, so that the torque of the rotation process becomes smaller, power consumption becomes smaller, but makes the movement trajectory longer, time-consuming phase Bigger than that. The numerical simulation of Table 3 is verified. Can be found after optimization compared to optimize the consumption increased by 6%, power consumption by about 40%.

V. CONCLUDING

SCARA type of PTP industrial robots in the production process for a long time in the high-speed reciprocating state, the accuracy requirements are very high, so to ensure the accuracy of the end track and reduce energy consumption for reducing production costs, energy saving and environmental protection has a very important significance. In this paper, the Cartesian space trajectory is re-planned using a method of acceleration planning and arc transition, and the average instantaneous power and the time taken by one crawl are optimized for optimization.

The non - dominated sorting difference algorithm combined with the non - dominated sorting genetic algorithm and the difference algorithm is used to optimize the target model. Through numerical modeling and simulation, the optimization results are simple and clear. At the expense of a small amount of time, the system energy consumption is reduced by nearly 40%; multiple tests, the end of the trajectory movement and planning trajectory accurately correspond.

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