Trajectory Planning of Manipulator based on Improved Genetic Algorithm

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Abstract. Laser cladding technology has been used in many applications, and repair of high-value broken drills is one of them. Aiming at the problem of trajectory planning of cladding repair access sequence in multiple damaged areas of the drill bit, the trajectory planning of the cladding path is based on an improved genetic algorithm. Firstly, the modified D-H representation was used to model the manipulator, and the kinematics analysis was performed. Based on this, an improved genetic algorithm is used to select the optimal order of multiple damaged areas for the damaged parts that need to be repaired. In order to avoid falling into the local optimum, adaptive genetic operators are used, and an evolution reversal step operation is added to improve the search ability. Finally, the fifth-order polynomial interpolation method is used in joint space for trajectory planning. After simulation analysis, the path points obtained through genetic algorithm optimization can smoothly perform cladding repair operations in various areas.

1. Introduction
Remanufacturing is an effective means of recycling waste products and one of the most promising technologies in the world[1]. When the laser cladding robot is used to repair and strengthen the failed parts, because the damage location of the workpiece is generally random, there will be multiple area damage in the working face of the parts, so the path planning for the random multi damage location repair is the cladding robot An important part of intelligence.

In the process of the laser equipment driven by the mechanical arm repairing the damaged parts, many researchers have carried out the repair path planning and research. J. Liu [2] proposed a method to repair the damaged parts of free-form surface, and provided a way of cladding. Although many scholars have put forward effective cladding path method, the path planning for multiple damaged areas has not been studied in depth. Fares [3] et al. (Spain) used the two constraints of the minimum moving distance and the optimal time of the end effector to solve the problem of collision free path planning of industrial manipulator by using genetic algorithm. Han T [4] et al. (Spain) used the time, space distance and track length as optimization indexes to realize the path planning of obstacle avoidance of the manipulator. Zong Y J [5] adds the local annealing operation to the genetic algorithm to avoid the problem of local optimization in the process of path planning. Genetic algorithm is more used in the path planning process of the manipulator to avoid obstacles. These studies are aimed at the application of the algorithm to avoid obstacles in the movement process of the manipulator. There is no path planning algorithm for the specific scene of cladding repair.

In this study, aiming at the problem of access sequence path planning for the cladding repair of...
multiple damaged areas of drill bit, a path planning method for multiple damaged areas of damaged parts based on the improved genetic algorithm is proposed, and the path planning in joint space is carried out by using the quintic polynomial interpolation method to verify the rationality of path points after planning.

2. Problem description
Motion planning includes path planning and trajectory planning. Two motion planning problems are faced in the process of mechanical arm cladding repair, which are the cladding sequence problem of multi area damage location and the trajectory planning problem between damage locations [6]. The main problem of this paper is to study the path planning of the end of the manipulator for multiple damaged areas on the basis of locating the damaged parts. After determining the path planning of the end actuator, the path planning between the damaged parts is studied. The simplified position point of each damaged area is known, and the position point of each damaged area is traversed to find the optimal path. Finally, the total stroke of the end cladding actuator of the mechanical arm is the shortest. In this paper, the mechanical arm driven laser equipment is used to simplify the modeling of cladding repair of damaged parts. As shown in Figure 1.

![Figure 1. Manipulator repair model.](image1)

In Figure 1, the red circle indicates the position point of the damaged part, and the blue arrow indicates the direction vector, that is, the posture direction of the manipulator during the cladding operation.

3. Kinematic model of manipulator
The manipulator studied in this paper is KUKA kr20 industrial manipulator. Perform kinematic model analysis.

The z-axis is in the direction of rotation according to the right-hand rule, the x-axis is in the direction of the common vertical line of the adjacent z-axis, the y-axis is obtained according to the right-hand rule of the Cartesian coordinate system, and the established linkage coordinate system is shown in Figure 2.

![Figure 2. modified D-H coordinate system of manipulator.](image2)
According to figure 2, the values of parameters in Table 1 of the improved D-H parameters can be directly calculated, where $\theta$ is the joint angle, $\alpha$ is the connecting rod angle of the mechanical arm, $a$ is the length of the connecting rod between adjacent joints, and $d$ is the offset of the connecting rod between adjacent joints.

| $i$ | $a_{i-1}$/mm | $\alpha_{i-1}$/rad | $d_i$/mm | $\theta_i$ |
|-----|--------------|------------------|-----------|-----------|
| 1   | $a_0 = 0$    | 0                | $d_0 = 0$ | $\theta_1$ |
| 2   | $a_1 = 160$  | $-\pi/2$         | $d_1 = 520$ | $\theta_2$ |
| 3   | $a_2 = 780$  | 0                | $d_2 = 0$ | $\theta_3$ |
| 4   | $a_3 = 150$  | $-\pi/2$         | $d_3 = 860$ | $\theta_4$ |
| 5   | $a_4 = 0$    | $\pi/2$          | $d_4 = 0$ | $\theta_5$ |
| 6   | $a_5 = 0$    | $-\pi/2$         | $d_5 = 0$ | $\theta_6$ |

The homogeneous transformation matrix from the base coordinate system to the end actuator is:

$$^{0}T_6 = ^{0}T_1(\theta_1) \cdot ^{1}T_2(\theta_2) \cdot ^{2}T_3(\theta_3) \cdot ^{3}T_4(\theta_4) \cdot ^{4}T_5(\theta_5) \cdot ^{5}T_6(\theta_6)$$

(1)

The inverse kinematics solution of the manipulator is opposite to the forward kinematics solution, but there are many solutions in the inverse kinematics solution, so it is necessary to optimize the inverse kinematics solution.

4. genetic algorithm

In the process of laser cladding repair of damaged bits, the processing order of each damaged area is determined by genetic algorithm, and the center points of each cladding area are treated as a separate point, and then the processing order is determined by genetic sequencing.

4.1. Fitness function

Fitness function is the basis of genetic operation, as a standard to evaluate each individual in the group. The fitness function is the reciprocal of its objective function in the path planning of cladding repair in multiple damaged areas of drill bit, and the objective of optimization is to select the chromosome with the largest fitness function value. That is to say, the distance of laser equipment driven by mechanical arm moving in each cladding area needs to be as small as possible. Where: $f_q$ is the fitness index of individual gene.

$$f_q = \left( \sum_{i=1}^{n-1} \sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2} \right)^{-1}$$

(2)

4.2. Genetic manipulation

4.2.1. Crossover and mutation operations. When the population fitness tends to be consistent or locally optimal, the values of the initial crossover rate $P_c$ and the initial mutation rate $P_m$ are increased to increase the probability of individual crossover and mutation, and jump out of the local optimum. When population fitness differs greatly, lower $P_c$ and $P_m$ are used.

$$P_c = \begin{cases} 
0.84 \left( \frac{f_{\text{max}} - f_{\text{higher}}}{f_{\text{max}} - f_{\text{avg}}} \right) & \text{if } f_{\text{higher}} \geq f_{\text{avg}} \\
0.9 & \text{if } f < f_{\text{avg}} 
\end{cases}$$

(3)

$$P_m = \begin{cases} 
0.09 \left( \frac{f_{\text{max}} - f}{f_{\text{max}} - f_{\text{avg}}} \right) & \text{if } f \geq f_{\text{avg}} \\
0.05 & \text{if } f < f_{\text{avg}} 
\end{cases}$$

(4)
4.2.2. **Evolutionary reversal operation.** "Evolution" refers to the unidirectionality of reversal operator, that is to say, only after reversal, can the fitness value be accepted, otherwise the reversal is invalid.

4.3. **Simulation experiment**

Need to obtain the location point of the broken bit based on the base coordinate point of the robot arm. When performing cladding operations on the damaged areas of the bit, the cladding of each damaged area is first sorted. The initial population of the genetic algorithm is \( M = 100 \), the initial crossover rate is \( P_c = 0.9 \), and the initial mutation rate is \( P_m = 0.05 \). Figure 3 shows the relationship between the number of iterations of the genetic algorithm and the convergence result at the location of the processing area. Compared with the genetic algorithm before the improvement, it can be concluded that the number of convergence of the improved genetic algorithm is reduced from 16 to 14, and the required quality is also significantly improved, avoiding the local optimal solution.

![Figure 3. Convergence comparison chart of genetic algorithm.](image)

5. **Trajectory planning**

In the application of industrial robots, the problem of trajectory planning has always been a research hotspot. Trajectory planning is to calculate the expected trajectory according to the requirements of the task. According to the different planning space, robot trajectory planning can be divided into joint space trajectory planning and Cartesian space trajectory planning. The Cartesian space is easy to lead to the singularity and redundancy of the manipulator, while the joint space oriented method is often used because of its small computation, easy real-time control and less singularity.

Limited to the length of this paper, this study only discusses the trajectory planning method of robot joint space. Joint space trajectory planning mainly involves the selection of joint interpolation function under all constraints. Because the welding repair operation of the manipulator is the track planning between the point-to-point, and the position, velocity and acceleration of the joint are specified at each start point and the end point, the quintic polynomial interpolation function is used for the track planning.
Figure 4. Change curve of manipulator joint.

\[ \theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5, \quad t \in [0, T] \]  

The boundary conditions are as follows:

\[ \theta_0 = a_0 \]  
\[ \theta_T = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + a_4 T^4 + a_5 T^5 \]  
\[ \dot{\theta}_0 = a_1 \]  
\[ \dot{\theta}_T = a_1 + 2a_2 T + 3a_3 T^2 + 4a_4 T^3 + 5a_5 T^4 \]  
\[ \ddot{\theta}_0 = 2a_2 \]  
\[ \ddot{\theta}_T = 2a_2 + 6a_3 T + 12a_4 T^2 + 20a_5 T^3 \]  

The solution of \( a_0 \), \( a_1 \), \( a_2 \), \( a_3 \), \( a_4 \), \( a_5 \) can be obtained by combining the above equations.

\[ a_0 = \theta_0 \]  
\[ a_1 = \dot{\theta}_0 \]  
\[ a_2 = \ddot{\theta}_0 / 2 \]  
\[ a_3 = (20\theta_T - 20\theta_0 - (8\dot{\theta}_T + 12\ddot{\theta}_0)T - (3\dddot{\theta}_0 - \dddot{\theta}_T)T^2) / (2T^3) \]  
\[ a_4 = (30\theta_0 - 30\theta_T - (14\dot{\theta}_T + 16\ddot{\theta}_0)T + (3\dddot{\theta}_0 - 2\dddot{\theta}_T)T^2) / (2T^4) \]
According to the modified D-H parameters, the corresponding joint angle $\theta_i$ is obtained by inverse solution of each damaged position. Here, two positions and positions are taken as representatives. Through the inverse solution of robot, the joint angles are obtained as follows:

$$\theta_{P_1} = \left[\frac{\pi}{6}, 0, \frac{2\pi}{3}, \frac{\pi}{3}, 0, \frac{\pi}{4}\right]$$

$$\theta_{P_2} = \left[\frac{\pi}{2}, \frac{\pi}{6}, 0, 0, -\frac{\pi}{2}, \frac{3\pi}{4}\right]$$

The joint angles of $\theta_{P_1}, \theta_{P_2}$ are substituted into quintic polynomials, and the angular velocity and acceleration are set as 0 and 0 respectively. Use matlab to draw the motion curve of each joint, as shown in the figure 4.

It can be seen that the joint position, velocity and acceleration of the interpolation output during the cladding operation of the manipulator are smooth.

6. Conclusion

According to the characteristics of laser cladding to repair broken drill bits, an improved genetic algorithm was used to sort the cladding order of multiple damaged areas. It was found through experiments that after genetic algorithm planning, the processing path was greatly shortened and the overall cladding efficiency was improved. Based on the analysis of the kinematics of the manipulator, two points of the drill bit damage area were extracted for trajectory planning, and the fifth-degree polynomial interpolation function was used to realize the trajectory planning of the manipulator in joint space. The simulation results show that the fifth-degree polynomial interpolation the trajectory planning effectively realizes the continuous and smooth space movement of the manipulator.

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