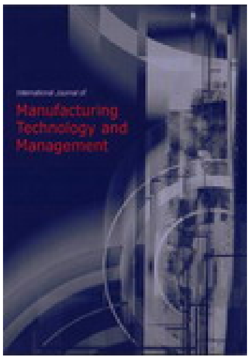

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Path planning method of industrial intelligent welding robot based on cuckoo search algorithm

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Abstract: In order to overcome the problems of large time cost and low planning accuracy of traditional path planning methods, a path planning method of industrial intelligent welding robot based on cuckoo search algorithm is designed. Firstly, the coordinate system of industrial intelligent welding robot motion and the kinematic model of industrial intelligent welding robot are constructed by using D-H parameter method. Then, the non-collinear points are set in the running space of the welding robot, the running radius of the welding robot is calculated according to the determined centre of the circle, and the obstacle location is completed. Finally, the limited conditions of welding path planning of welding robot are set, and the cuckoo search algorithm is used to optimise the optimal welding path of robot. The experimental results show that the proposed method can effectively improve the efficiency and accuracy of path planning of industrial intelligent welding robot.

Keywords: cuckoo search algorithm; industrial intelligent welding robot; route planning; D-H parameter method.

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1 Introduction

With the continuous deepening of manufacturing in the field of social production, intelligent production has made great progress and continuously improved the efficiency of industrial production. Intelligent robots play an important role in various industrial fields (Zhang, 2021). With the continuous advancement of the wave of global automatic manufacturing industry, the sustainability, accuracy and resistance to harsh working environment of industrial intelligent welding robot have become the biggest advantages in production. Welding is one of the important process forms in manufacturing industry, which is widely used in automobile industry, shipbuilding and other fields (Shimanuki and Axelrod, 2021). With the development of numerical control technology, welding has become a basic process means for accurate manufacturing in the current industrial field (Manav and Lazoglu, 2021). Welding robot has been widely used in welding production line. Compared with traditional welding machine production line, welding robot not only improves the flexibility of production line, but also greatly improves the production efficiency of products. Welding robot refers to an industrial robot engaged in welding (including cutting and spraying). Its body has the advantages of multi degrees of freedom and high flexibility (Xue et al., 2020). However, with the increasing complexity of welding environment and some welding parts, the requirements of welding robot are higher and higher. When the industrial intelligent welding robot carries out welding, it is affected by the path, obstacle points and other factors, which leads to certain errors in the welding parts and affects the work efficiency of industrial production (Zhang and Han, 2021). Therefore, in the operation process of intelligent welding robot, it is necessary to effectively plan its path and improve the working ability of the robot. Therefore, researchers in this field have done a lot of research and achieved some results.

Nie and Zhao (2021) designed a path planning method of welding robot based on improved Drosophila algorithm. This method realises the research purpose with the help of the improved Drosophila algorithm. In the path planning of welding robot, OFOA is used to improve the adaptive step size of its operation, and fireworks explosion operation is carried out in the Drosophila algorithm to enhance the optimisation advantages of the Drosophila algorithm. The improved algorithm designs the operation path of industrial welding robot. The planned path operation of this method is relatively stable, but the environmental factors considered are ideal. There are some differences in the actual environment, and there is a problem of poor accuracy in path planning. Sun et al. (2020) designed an intelligent path planning method for cooperative welding of three-dimensional complex components with two robots. This method mainly studies the construction of welding robot running path by large and complex machinery. By designing the cooperative model of welding robot in the three-dimensional space of parts, unifying it, and dividing the part structures in different three-dimensional space, and then determining the optimal path in the welding block with the help of ant colony algorithm.

This method divides the three-dimensional space parts of complex structure locally, and then plans the welding path. The path planning effect of this method is good, but the work efficiency is not high, and there are some limitations. Ruan et al. (2022) designed a path planning method of mobile robot based on AHMRRT. In this method, multiple random trees such as the starting point and target point of the running path of the welding robot are designed under the multi random tree strategy, and each tree is expanded to improve the efficiency of setting the target point. Then, an adaptive heuristic bias factor is added through a single random tree to continuously update the nodes of the obstacles in the welding environment, and a free space is designed to quickly determine the obstacle points in the path planning, finally, the intelligent path planning of welding robot is realised by optimising the path planning results by random sampling function. This method determines the obstacle points in the path planning according to the actual environment and realises the effectiveness of the planned path, but the determination of the obstacle points in the planning wastes more time and has some shortcomings.

Therefore, this paper designs a path planning method of industrial intelligent welding robot based on cuckoo search algorithm, in order to improve the efficiency of path planning of industrial intelligent welding robot. The main technical route of this paper is:

Step 1 With the help of D-H parameter method, construct the coordinate system of industrial intelligent welding robot motion, calculate the kinetic energy and the joint hinge control force parameters of the manipulator in the welding robot motion, construct the kinematic model of industrial intelligent welding robot, and complete the motion analysis of industrial intelligent welding robot.

Step 2 According to the kinematics analysis results of the welding robot, determine the known space points, describe the running posture of the welding robot through the Euler angle, determine the trajectory in the running space of the welding robot, set the non-collinear points in the running space of the welding robot, calculate the running radius of the welding robot according to the determined centre of the circle, locate the centre point of the obstacle material in the space, and complete the obstacle positioning;

Step 3 Based on the positioning results of obstacles, determine the advantages of cuckoo search algorithm, set the limited conditions for welding path planning of welding robot, determine the robot welding path, and use cuckoo search algorithm to optimise the robot welding optimal path, so as to realise the path planning of industrial intelligent welding robot.

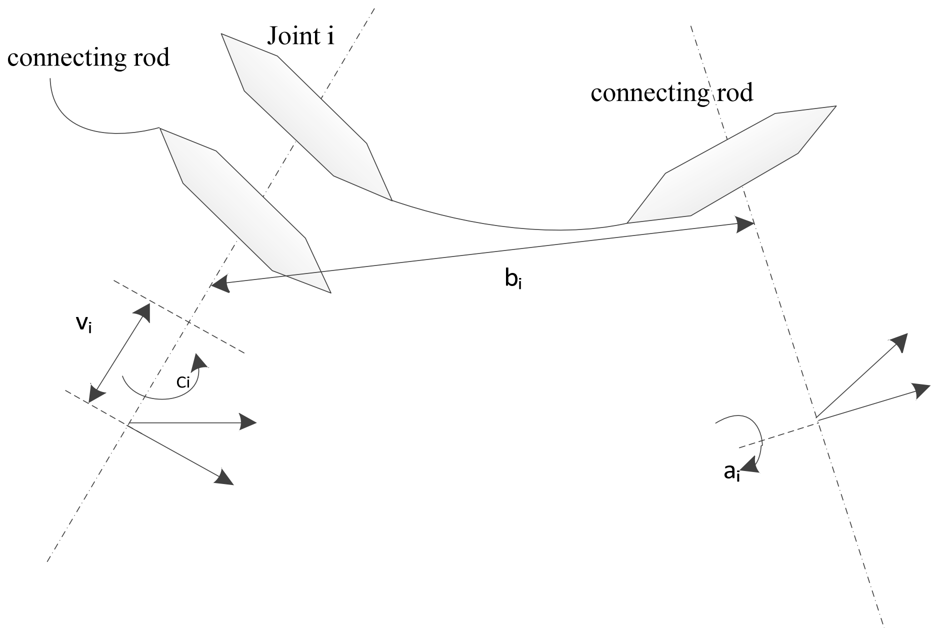
Step 4 Experimental analysis.

2 Design of path planning method for industrial intelligent welding robot based on cuckoo search algorithm

2.1 Kinematics analysis of industrial intelligent welding robot

Before the path planning of industrial intelligent welding robot in industrial production, it is necessary to analyse the kinematics of intelligent welding robot. Therefore, in order to improve the follow-up robot path planning, this paper first analyses the kinematics of the industrial intelligent welding robot and determines the basic principle of the operation of the industrial intelligent welding robot. In the kinematics analysis of industrial intelligent welding robot, the coordinate relationship between the robot end effect or and its running joint is mainly analysed. Therefore, the relationship between the end and the actuator needs to be determined first. Firstly, this paper constructs the motion coordinate system of industrial intelligent welding robot with the help of D-H parameter method (Dewangan et al., 2020). The motion coordinate system of industrial intelligent welding robot is shown in Figure 1.

Figure 1 Construction of motion coordinate system of industrial intelligent welding robot by D-H parameter method



In Figure 1, *i* represents the joint point of the robot motion joint coordinate system fixed in the whole robot. The link connects the joint and the joint, connects the moving joint drive connecting rod to each other, and realises the welding work according to its movement. In the robot coordinate system of the design, the basic parameters include: robot running joint distance v_i, a_i is joint Angle, b_i is joint link length and connecting rod torsion Angle. In this coordinate system, the operation relationship between adjacent joints is determined through the homogeneous change matrix, and the coordinate system of the welding robot is as follows:

$$W_i = Rot(i)\begin{bmatrix} \cos c_i - \sin c_i \cos a_i & \sin c_i \cos a_i \\ \sin c_i \quad \sin c_i \cos a_i & -\cos c_i \cos a_i \\ \sin b_i \cos v_i \quad \sin c_i \cos a_i & -\sin c_i \cos a_i \end{bmatrix} \tag{1}$$

Specifically, W_i represents the coordinate homogeneous change matrix of the welding robot.

According to the coordinate homogeneous change matrix (Pashna et al., 2020) of the welding robot determined above, the kinetic energy in the motion of the welding robot is determined according to its motion law in the coordinate system, and the following is obtained:

$$D=\sum_{i=1}^{n}\left(\frac{1}{2}A_ie_i^2+\frac{1}{2}o_iq_i^2\right) \quad (2)$$

Among them, A_i represents the motion speed of the welding robot, e_i^2 represents the changing angle value of the robot joint coordination movement, o_i represents the kinetic energy factor of the welding robot, and q_i^2 represents the rotation angle value of the robot joint link.

In the overall motion of intelligent welding robot, its motion attitude is different from that of other robots, and its manipulator joint joint needs to be strictly controlled. The control formula is:

$$U=\sum\left(u_o,u_1,u_2\right)^T \quad (3)$$

Among them, U represents the control force limit range of the mechanical arm joint hinge, and T represents the transpose symbol.

According to the research on the motion of the intelligent welding robot analysed above, the overall kinematics model of the welding robot is determined, and the motion law of the robot operation is determined through the constructed motion model of the welding robot (Lee et al., 2020), and the following results are obtained:

$$V(x)=\sum G\left(\frac{q_a}{\sigma}\right)+u_p \quad (4)$$

Among them, $V(x)$ represents the inertia matrix of the welding robot operation, and u_p represents the centrifugal force vector of the robot.

In the kinematics analysis of industrial intelligent welding robot, the coordinate system of industrial intelligent welding robot motion is constructed with the help of D-H parameter method, the kinetic energy and the joint hinge control force parameters of manipulator in the motion of welding robot are calculated, and the kinematics model of industrial intelligent welding robot is constructed.

2.2 Obstacle location in path planning of industrial intelligent welding robot

Based on the above kinematics analysis of industrial intelligent welding robot, in order to realise the path planning of industrial intelligent welding robot, it is necessary to locate the obstacle points in the existing operation path, and design the obstacle avoidance path according to the determined positioning points to improve the effectiveness of path planning of industrial welding robot. In the running path of the welding robot, in its running spatial coordinate system, determine the known two points in space, describe the running attitude of the welding robot through Euler angle, and set the known two points as:

$$p_1=q\left[x_1,y_2,z_1,a_1,b_1,c_1\right]l \quad (5)$$

$$p_2=q\left[x_1,y_2,z_1,a_1,b_1,c_1\right]l \quad (6)$$

where the interpolation point is q, l representing the normalised interpolation factor.

At this time, the path trajectory in the running space of the welding robot is determined as follows:

$$p' = \begin{cases} x = x_1 + \rho\Delta x \\ y = y_1 + \rho\Delta y \\ z = z_1 + \rho\Delta z \\ a = a_1 + \rho\Delta a \\ b = b_1 + \rho\Delta b \\ c = c_1 + \rho\Delta c \end{cases} \tag{7}$$

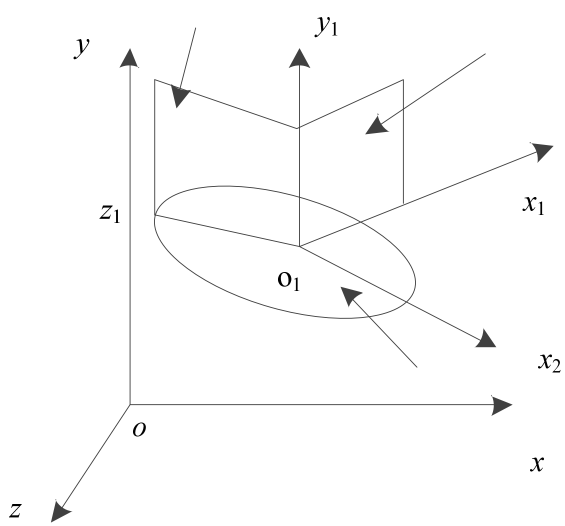
Among them, $x/\Delta y/\Delta c/\Delta a/\Delta b/\Delta c$ represents the total increment of the robot running position.

According to the preliminarily determined running track, the homogeneous matrix of the robot in the space is constructed, and the space state of its initial path is determined. The following results are obtained:

$$K = \begin{bmatrix} x \\ y \\ d \\ 1 \end{bmatrix} \tag{8}$$

where K represents the spatial state matrix of the initial path, and d represents the coordinate point position in the matrix.

Figure 2 Schematic diagram of arc running path of welding robot



Welding robot in the welding path to ensure the starting point and the welding end path environment smooth, in its running with trapezoidal speed, set in the coordinate space near the known two points add two parabolic (Cao et al., 2021), make its speed constant, set it to r, at this time, the speed of linear motion is v, then two running path is expressed as:

$$f_p = \frac{v}{r} \tag{9}$$

$$h_p = \frac{1}{2} r f_p^2 \tag{10}$$

where v represents the robot running speed, and p represents the intermediate running displacement amount of the robot.

According to the determined initial running path, set that there are three non-collinear points in the running space of the welding robot. Assuming that the coordinates of the points are known, a segment of arc path of the welding robot can be determined at this time, as shown in Figure 2.

According to Figure 2, set the arc coordinate system as:

$$\begin{vmatrix} x - x_1 & y - y_1 & z - z_1 \\ x - x_2 & y - y_2 & z - z_2 \\ o - o_1 & x_1 - x_2 & \end{vmatrix} = 0 \tag{11}$$

Determine the centre of the space circle in the arc, set to $u_0 = [x_1, y_1, z_1]$, and then the centre coordinate of the space circle in the arc is:

$$\begin{bmatrix} n_{11} \\ n_{21} \\ n_{31} \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} & n_{22} & n_{23} \\ n_{31} & n_{32} & n_{33} \end{bmatrix} \tag{12}$$

The running radius value of the welding robot is calculated according to the determined circle centre. According to the determination of the radius, the centroid point of the obstacle in the space is located. The calculation formula of the running radius value of the welding robot is:

$$e_i = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2} \tag{13}$$

Among them, e_i represents the running radius value of the welding robot, and $x_0/y_0/z_0$ represents the different axis coordinate points of the centre of the circle.

According to the determined operating radius, the obstacle point coordinates (Jamwal et al., 2020) in the radius are determined with the help of cosine calculation method, and the fault free position is determined. The following results are obtained:

$$^{o}\mathrm{F}_i = \left| \frac{n_{11}}{\sqrt{n_{11}^2 + n_{12}^2 + n_{13}^2}} \right| g_i \tag{14}$$

where g_i represents the obstacle coordinate point.

In the path planning of industrial intelligent welding robot, in the obstacle point positioning, determine the known space points, describe the running posture of the welding robot through Euler angle, and determine the trajectory in the running space of the welding robot. According to the determination of the initial running path, set that there are three non-collinear points in the running space of the welding robot, calculate the running radius of the welding robot according to the determined circle centre, and locate the obstacle material centre point in the space, complete the obstacle location in the path planning of industrial intelligent welding robot.

2.3 Path planning method of industrial intelligent welding robot based on cuckoo search algorithm

Cuckoo search algorithm is a heuristic bionic swarm intelligent optimisation algorithm by simulating the biological behaviour of cuckoo birds, which uses the special breeding mode of cuckoo birds to find the optimal solution of the problem (Hao et al., 2020). In this process, cuckoos choose their nests before laying eggs, and choose the best geographical location by nesting. Therefore, this paper realises the path design with the help of modified algorithm.

The path and location update formula of cuckoo nesting is as follows:

$$K_i^{t+1} = K_i^t + \vartheta levy(\tau) \tag{15}$$

In the formula, K_i^t is the i^{th} solution of generation t; ϑ represents the step length control factor, $levy(\tau)$ represents the mechanism. A constant greater than zero is used to control the range of random cuckoo search. In order to obtain more useful step length information for the optimal solution, the step length is calculated as follows:

$$\delta = \theta_0 \left(K_i^t - K_{best}^t \right) \tag{16}$$

where θ_0 is a constant; K_{best}^t represents the optimal solution of the current generation t generation.

In this paper, the path planning of intelligent welding robot is realised with the help of cuckoo search algorithm. In order to realise path planning quickly, this paper solves the welding path planning problem of a single welding robot. In this planning process, the following assumptions are made:

1 The welding robot keeps a uniform motion in the process of spot welding each spot.

2 The influence of the production beat time of the welding station on the path planning of the welding robot is not considered temporarily.

3 The spot welding time of different types of welds is the same.

4 For the time being, the interference between the motion process of the welding robot and the equipment during the execution of the welding task is not considered. The solution can be proposed according to the specific situation of the later simulation to optimise the welding path.

In the operation path planning of intelligent welding robot, its operation path is described in the form of directed graph, that is:

$$S = (G, H, U) \tag{17}$$

where G represents the vertex of the welding path, H represents the starting point of the initial state of the welding, U represents the edge set of the welding points, and S represents the welding Curie point matrix.

According to the above designed path planning digraph, it is weighted to determine an obstacle free path. The obtained path planning objective function is:

$$\gamma_{ij} = \begin{cases} 1, ij \text{ } In \text{ } circuit \\ 0, other \end{cases} \tag{18}$$

During its operation, the constraint conditions of the robot welding path need to be set during the path planning process (Taghavifar and Rakheja, 2020), which is convenient for the robot path planning. The set constraint conditions are:

$$\text{minu} = \sum_{i \neq j} \gamma_{ij} d_{ij} \tag{19}$$

Specifically, minu represents the shortest path travelled in the welding run and d_{ij} represents the path-weighted matrix.

According to the determined constraints, the cuckoo search algorithm is introduced to set the shortest path of the welding robot for optimisation. The final optimisation result is the path planning result of the welding robot, and the following results are obtained:

$$\varphi = \left\{ \left(d_{ij} \left| \sum_{i \in k} \sum_{i \in k} \beta_{ij} \mu, k \in \{1, 2, 3 \ldots N\} \right. \right) \right. \tag{20}$$

Among them, φ represents the optimal result of the intelligent welding robot path planning, β_{ij} represents the optimal target function in the cuckoo search algorithm, and μ represents the key point of the generating path.

In the design of path planning method of industrial intelligent welding robot, the advantages of cuckoo search algorithm are determined, the limited conditions of welding robot welding path planning are set, the robot welding path is determined, and the cuckoo search algorithm is used to optimise the robot welding optimal path to realise the path planning of industrial intelligent welding robot.

3 Experimental analysis

3.1 Experimental scheme design

In the experiment, the welding robot of an automobile parts manufacturing enterprise is used as the research object, and the design algorithm of this paper is used to study the welding robot. With the aid of the welding robot for path planning, the actual sample welding robot is shown in Figure 3.

Figure 3 Actual working condition of sample welding robot (see online version for colours)

The specific experimental parameters are shown in Table 1.

Table 1 Relevant experimental parameters

Parameter	*Concrete content*
Welding robot model	HY1006A-135
Number of axes	6
Drive capacity/w	4050
Positional repeatability /mm	0.1
Base shaft maximum speed/°s	180
Drive control mode	AC servo motor
Speed control	TCP constant speed control
Ambient temperature/°	0-45
Ambient humidity/°	20-80
Source/KVA	1.5
Planning times	100
Obstacle/bar	50

3.2 Experimental index design

Before the experiment, in order to improve the reliability of the simulation experiment and the authenticity of the experimental results, the experimental indicators are set according to the above experimental environment. In the experiment, the welding path planning time cost, planning accuracy and obstacle avoidance error are analysed as the experimental indicators. In the experiment, the effectiveness of the design method is verified by comparing the method in this paper, the method in Sun et al. (2020) and the method in Ruan et al. (2022).

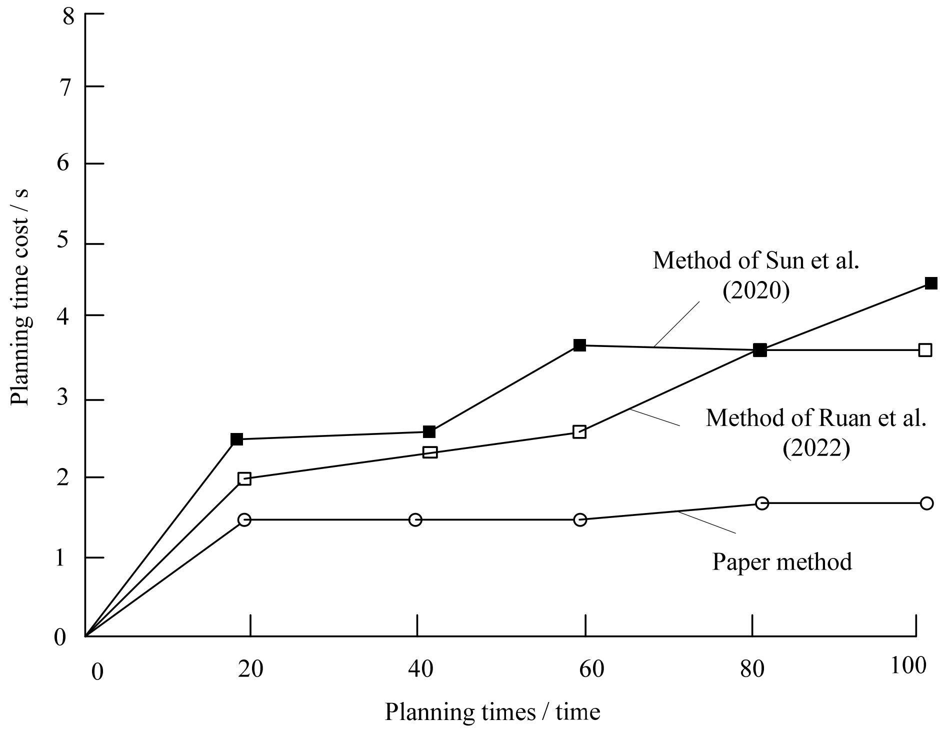
3.3 Analysis of experimental results

3.3.1 Time cost analysis of different path planning methods

In the experiment, the time cost of welding robot path planning is analysed by using the methods of this paper, Sun et al. (2020) and Ruan et al. (2022). Among them, in the same experimental environment, the shorter the time cost of the set fixed path planning, the faster the representative planning speed. The experimental results are shown in Figure 4.

By analysing the experimental results in Figure 4, it can be seen that there are some differences in the time cost of welding robot path planning by using the methods of this paper, Sun et al. (2020) and Ruan et al. (2022). Among them, the planning time cost of this method is the shortest, and the time cost of this method is always less than 2s, which is shorter than that of the other two methods. It is verified that the planning speed of the proposed method is better than that of the other two methods.

Figure 4 Time cost analysis of different path planning methods



3.3.2 Accuracy analysis of path planning with different methods

In the experiment, the accuracy of welding robot path planning is analysed by using the methods of this paper, Sun et al. (2020) and Ruan et al. (2022). The results are shown in Table 2.

Table 2 Accuracy analysis of path planning by different methods (%)

Planning times/times	*The method of this paper*	*Sun et al. (2020) methods*	*Ruan et al. (2022) methods*
20	95	89	85
40	96	87	82
60	96	87	81
80	95	85	81
100	96	84	80

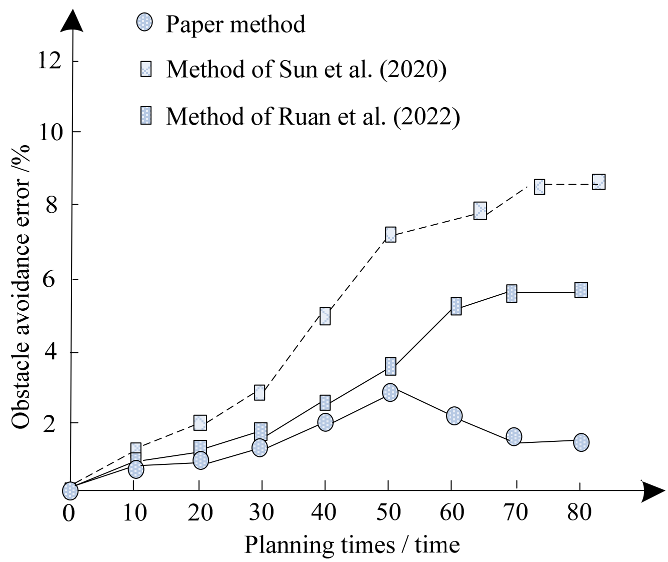
By analysing the accuracy of this method, Sun et al. (2020) method and Ruan et al. (2022) method, there are some differences in the results. Among them, the accuracy of welding robot path planning in this method is always higher than 95%, while the planning accuracy of other methods is lower. Compared with this method, this method has more advantages.

3.3.3 Error analysis of obstacle avoidance with different methods

Based on the above analysis, the error analysis of obstacle avoidance in path planning of welding robot is analysed by using the methods of this paper, Sun et al. (2020) and Ruan et al. (2022). The results are shown in Figure 5.

By analysing the experimental results in Figure 5, it can be seen that there are different errors in obstacle avoidance of welding robot in path planning by using the methods of this paper, Sun et al. (2020) and Ruan et al. (2022). Among them, the error of obstacle avoidance in path planning of welding robot using this method is low and always less than 3%. The method of Sun et al. (2020) and the method of Ruan et al. (2022) analyse that the error of obstacle avoidance in path planning of welding robot is higher than that of this method, and verify the effectiveness of the proposed method.

Figure 5 Obstacle avoidance error analysis of different methods (see online version for colours)



4 Conclusions

Industrial intelligent welding robot plays an important role in improving industrial production efficiency. This paper designs a path planning method of industrial intelligent welding robot based on cuckoo search algorithm. With the help of D-H parameter method, the motion coordinate system of industrial intelligent welding robot is constructed, the kinematics model of industrial intelligent welding robot is constructed, and the kinematics analysis of industrial intelligent welding robot is completed. Determine the known space points, describe the running posture of the welding robot through the Euler angle, set the non-collinear points in the running space of the welding robot, calculate the running radius of the welding robot according to the determined centre of the circle, locate the centre point of the obstacle material in the space, set the limited conditions of the welding path planning of the welding robot, determine the robot welding path, and use the cuckoo search algorithm to optimise the optimal welding path of the robot, realise the path planning of intelligent welding robot in welding industry.

The experimental results show that the proposed method can effectively improve the efficiency of path planning of industrial intelligent welding robot, and it is feasible to improve the path planning of welding robot.

Acknowledgements

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