Coordinated motion analysis and simulation of arc welding robot and positioner

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Abstract: Direct at the problem of coordinated motion of the arc welding robot positioner, the motion between the arc welding robot and the positioner is required to be strongly coupled during the process of planning weld movement. In order to express this characteristic, in this article the coupling mathematical model of arc welding robot and positioner is established. The motion equation is simulated by MATLAB neural network in the MATLAB simulation software environment. The simulation results show that the constructed model can accurately reflect the accuracy of the arc welding robot positioner coupling motion.

1. Introduction
The coordination between the positioner and the robot makes the flat, transverse, vertical and faceup problems in the welding process attribute to the flat welding process. The best position to be welded mentioned in the paper refers to the horizontal position of the weld [1]. In order to enhance the welding strength, reduce the complexity of the welding process, and thus improve the quality and efficiency of welding [1], the arc welding robot and the positioner should achieve coordinated motion. Therefore, it is very important to establish the corresponding mathematical model and carry out theoretical analysis of the model.

Each functional module in the work system of the arc welding robot positioner can build up a corresponding mathematical model, but lots of mathematical formulas need to be used in the established mathematical model. It is not realistic to calculate by hand, nor can it see the interaction effect between robot positioners. For the purpose to intuitively understand the coupling performance between the robot positioners, the established mathematical model is simulated.

MATLAB software is the product of computer technology and mathematical theory development, with powerful function especially in matrix computing, and other software is difficult to compare. Therefore, it is widely used and plays a more and more important role in modern industrial production. This paper utilizes MATLAB software to simulate the established mathematical model and explore the offline programming method of arc welding robot positioner.

2. Theoretical foundation

2.1 Kinematics principle of arc welding robot positioner
A matrix operation can represent a point, a vector, a translational motion and a rotational motion of a specific coordinate system. In practical engineering equipment, a matrix can represent the motion of
an object or other moving component in a coordinate system. In this paper, the matrix is used to represent the relative motion relationship between each functional module and each component of the arc welding robot positioner [3]. In this paper, a six-axis model robot is used as the research object.

The main parameters of the robot are: joint angle, connecting rod twist angle, connecting rod length, connecting rod distance and number of connecting rods. These parameters determine the motion range of the robot.

The working principle of the positioner is to drag the workpiece to be welded so that the weld seam is continuously moved to the optimal position to be welded. The main parameters of the positioner are: $\theta_a$ and $\theta_b$, representing the two joint angles. In order to facilitate the analysis, when constructing a mathematical model of kinematics, the positioner is often selected as part of the arc welding robot system.

According to the DH description method, the parameters and mutual relations of each member are determined, and a coordinate system on each link is set. The matrix transformation principle is utilized to express the parameters and mutual relations of adjacent links, including the relationship between the welding gun and the solder joints to be welded of the positioner.

According to the DH description method, in the position transformation of each joint of the arc welding robot, the position and orientation matrix of the N+1 joint local coordinate system relative to the previous coordinate system N is expressed as follows:

$$A_{n+1} = \begin{bmatrix}
    C\theta_{n+1} - S\theta_{n+1}C\alpha_{n+1} & S\theta_{n+1}S\alpha_{n+1} & a_{n+1}C\theta_{n+1} \\
    S\theta_{n+1}C\alpha_{n+1} & C\theta_{n+1}S\alpha_{n+1} & a_{n+1}S\theta_{n+1} \\
    0 & S\alpha_{n+1} & d_{n+1} \\
    0 & 0 & 1
\end{bmatrix}$$

In order to write conveniently, C is used for cos and S for sin. In the working system of the arc welding robot positioner, during the continuous arc welding operation of the robot, although the solder joints of the welding seam move continuously with the movement of the positioner, the end of the welding gun always tracks the weld movement.

According to the homogeneous transformation description of Cartesian space [4], the motion equations of the welding gun and the positioner are expressed as follows:

$$W_H q_T \text{aim} = W_0 T_g \cdot W_0 T_1 \cdot W_1 T_g \cdot W_2 T_3 \cdot W_3 T_g \cdot W_4 T_5 \cdot W_5 T_g \cdot W_6 T_6 \cdot W_6 T_g$$

Equation (2-1) is the motion equation of the welding gun at the end of the arc welding robot; Equation (2-2) is the coordinate movement equation of the positioner to hold the workpiece to be welded. $W_H q_T \text{aim}$ represents a target position and orientation matrix of the solder joints to be welded; $W_0 T_q T_{aim}$ represents a target position and orientation matrix of the welding gun [10].

The parameters in Table 2-1 are substituted into equation (2-1), and it can be obtained through matrix manipulation that:

$$W_{H_q} T_{aim} = \begin{bmatrix}
    C(C_{2a}C_{2c} - S_{2a}S_{2c}) - S_{2a}C_{2c} & C(-C_{2a}C_{2c} - S_{2a}S_{2c}) + S_{2a}C_{2c} & C(C_{2a}S_{2c} + C_{2c}a + C_{2a}a) \\
    -S(C_{2a}C_{2c} - S_{2a}S_{2c}) + C_{2a}S_{2c} & S(-C_{2a}C_{2c} - S_{2a}S_{2c}) - C_{2a}S_{2c} & S(C_{2a}S_{2c} - C_{2c}a + C_{2a}a) \\
    0 & 0 & 1
\end{bmatrix}$$

At present, there are a target position and orientation matrix of the welding seam and a target position and orientation matrix of the welding gun. To achieve the coordinated movement of the arc welding robot and the positioner, when the orientation of the welding gun at the best position to be welded, the expression equation of the welding gun orientation is:
2.2 Motion mathematical model

If there is a space curve weld seam, the task of the arc welding robot positioner system converts the space curve weld seam into a horizontal motion by coordinating motion.

Let the equation of the space weld seam trajectory be:

\[ H_f = F(x, y, z) \]  \hspace{1cm} (2-4)

To carry out the welding of complex weld seams, the positioner should drag the welding workpiece to be welded to the optimal position of welding in real time, and the robot should constantly adjust the joint angles so that the welding gun can continue to weld the welding seam in a certain orientation. At this time, there is a real-time transformation between the positioner and the robot. This transformation is a matrix transformation, that is:

\[ W_{Hq}^T H_p T = W_{Hf}^T H_p T \]  \hspace{1cm} (2-5)

In the above formula \( W_{Hp}^T \) is the actual welding position matrix calculation of the weld, ideally horizontal.

\( H_f H_q T \) is a transformation matrix, with which the welding gun and the positioner can be realized. The transformation matrix can be written in a form of \( H_f H_q T = (f(\theta)_{ij}) \), in which the matrix element \( f(\theta)_{ij} \) is a function of time \( t \), i.e. \( f(\theta)_{ij} = R \cdot f(\omega t) \), \( R \) is a mechanical parameter and a constant. By calculating the instantaneous transformation amount at \( \Delta t \), the displacement transformation matrix can be derived [1].

\[ \frac{dH_{Hq}^T}{dt} = \frac{dH_{Hq}^T}{dt} \cdot df(\theta) \]  \hspace{1cm} (2-6)

\[ \frac{df(\theta)}{dt} = R \cdot f(\omega) \]. In the equation, \( \frac{df(\theta)}{dt} \) is the motion transformation matrix. For the equation (2-4), the welding seam equation is:

\[ H_f = F(x, y, z) \].

During the welding process, the rotational speed \( \omega \) of the positioner is a variable. After the time of \( \Delta t \), the speed operation of the curve can be written as a formula [9]. The following formula is to calculate the speed of the positioner dragging the workpiece to be welded when the welding gun moves along the arc of the welding seam.

\[ F'(x, y, z) = \frac{dH_{Hq}^T}{dt} \frac{df(\theta)}{dt} \cdot F(x, y, z) \]  \hspace{1cm} (2-7)

The orientation of the welding gun is set to an orientation of flat welding, and in the Y and Z planes is an equation:

\[ F'(x, 0, 0) = \frac{dH_{Hq}^T}{dt} \frac{df(\theta)}{dt} \cdot R \cdot f(\omega) \cdot F(x, 0, 0) \]  \hspace{1cm} (2-8)
where \( F'(x,0,0) = V_{x\tan} \), \( V_{x\tan} \) is the linear speed of the welding gun in the tangential orientation.

\[
V_{x\tan} = \frac{d H_f T}{df(\theta)} \cdot R \cdot f(\omega) \cdot F(x,0,0)
\]

(2-9)

Summarizing the above equations, as long as the motion speed \( V_{x\tan} \) is determined, the rotational speed \( \omega \) of the welding seam on the corresponding workpiece to be welded can be obtained.

3. Simulation of the motion equation model

3.1 Establishment of simulation based on neural network

Motion control based on neural network simulation. First, through the analysis of kinematics, to acquire a set of kinematics positive solution mathematical model and inverse solution model for a given robot; Secondly, to write a certain program, connect the positive solution and the inverse solution to each other, and perform simulation in the whole motion space. If the results of the positive and inverse solutions are consistent with each other, it means that the positive and negative solutions model obtained in the kinematics analysis are correct. However, once an inconsistency emerges, it indicates that there is a problem with this set of positive and negative solutions to the mathematical model equation, and often the problem arises on the mathematical model of the inverse solution [5].

This paper is based on the MATLAB neural network to simulate the kinematics model.

When simulating the trajectory of the weld seam and that of the welding gun, due to various reasons, such as the vibration of the positioner, the vibration of the welding gun itself, etc., the actual movement trajectory of the welding gun always cannot coincide with the trajectory of the weld seam. However, this error is allowed as long as the accuracy is within the allowable scope [6].

In order to facilitate the simulation, we give a data list for some special points in the actual welding [3]:

| i  | x | y |
|----|---|---|
| 1  | 9.5 | 5.8 |
| 2  | 5.8 | 4.6 |
| 3  | 4.6 | 2.8 |
| 4  | 2.8 | 1.1 |
| 5  | 1.1 | 1.2 |
| 6  | 1.2 | 2.6 |
| 7  | 2.6 | 3.1 |
| 8  | 3.1 | 4.  |

By processing these special points on the welding seam, MATLAB simulation software can obtain relatively smooth curve welding seams before the simulation process.

Utilizing the motion math model equations in the previous section and inputting the appropriate control program in MATLAB, the welding seam curves can be generated based on special points. By the MATLAB neural network, the simulation program is trained accordingly, including training information Training Info and training parameters Training [7]. Simulation graphics can be obtained through training.

3.2 Simulation effect analysis

Through the training of the parameters and the training of the control information, the motion situation of each system can be obtained.
The error range is analyzed to observe whether it is within the allowable range. It can be seen from Figure 3-1 that the motion time is between 0 and 5 seconds, and the fluctuation of the linear velocity of each motion ranges from 0 to 1.2, which can fully meet the requirement of accuracy.

Simultaneously, in the simulation process, the neural network system can be used to generate the operation diagram, shown as Figure 3-2.

Through the simulation of the coordinated motion of the arc welding robot and the positioner, the motion trajectory function \( P(\Delta \theta_i, \cdots, \Delta \theta_j, M) = N_{i+1} \) of the welding gun at the end of the arc welding robot is very easy to obtain. After simplification, the motion trajectory function of the welding gun can be classified into a plane with only a time parameter. Through the above analysis, we know that the process of kinematics simulation is: first, by the analysis of kinematics, a set of kinematics positive solution mathematical model and inverse solution model for a given robot are obtained; secondly, a certain program is written, and the positive solution and the inverse solution are connected to simulate in the whole motion space. If the results each step of the positive solution and inverse solution problem are consistent with each other, it means that the positive solution and inverse
solution model obtained in the kinematics analysis is correct. But once an inconsistency emerges, it indicates that the this set of positive and negative solutions thematical model equations go wrong.

By means of simulation, problems can be discovered in time, and theoretical guidance can be provided for the actual operation process.

4. Conclusions
The planning for the coordinated motion of the position and orientation of the welding gun and the position and orientation of the positioner is influenced by many factors, such as process parameters, workpiece shape and plate thickness, etc. Its final orientation is difficult to quantify accurately, so it must rely on a large amount of empirical knowledge accumulation. Therefore, the application of the mathematical model obtained from the coordinated motion of the arc welding robot and the positioner, greatly reduces the complexity of the operation.

Of course, in production applications, many other theoretical knowledges are resorted to, such as the methods of welding seam centerline information acquisition based on the welding seam features \(^8\); intelligent induction control to achieve the identification of welding seam \(^9\), etc.

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