



Research on Continuous Trajectory Planning of Industrial Welding Robot Based on CAD Technology

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Abstract. This proposed works aiming at the shortcomings of welding robot inverse kinematics that are difficult to solve and have multiple or no solutions. A trajectory planning method based on CADD CAM technology is proposed which combines cad three-dimensional modeling technology and cam post-processing technology to realize welding trajectory and welding gun pose. The curve interpolation calculation of the robot accurately obtains the motion parameters of each joint of the robot, and simulates the welding trajectory and the welding gun pose through the Matlab software. Through simulation verification, the change of the kinematic parameters of each joint of the welding robot is analyzed, and the theoretical mathematical model is carried out. The comparison verifies the accuracy and reliability of the data, and provides a theoretical basis for realizing the trajectory planning of different types of intersecting welds.

Keywords: Welding robot; Trajectory planning; Simulation

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1 INTRODUCTION

From the perspective of the application of parametric technology in mechanical product design, the development process of parametric technology has roughly gone through the following five stages: two-dimensional CAD stand-alone work; solid modeling technology and three-dimensional system development. In the 20th century, with the continuous research of robotics by scientific researchers, modern robots appeared for the first time in people's industrial production. This major change also opened the curtain of the rapid development of robots, representing that science and technology have begun to face productivity. Transformation is of great significance across the age. The emergence of robotics has brought a huge impact to traditional manufacturing. As a high-tech industry, robotics has changed the current production model and promoted the development of future manufacturing and society.

With the leap in science and technology in recent decades, robotics technology has also benefited a lot. After continuous improvement and improvement, robots have been well adapted to various industries and completed corresponding tasks, especially in the automotive field. The robot has basically realized the replacement of ordinary operators to complete various tasks [1]. Industrial robots are a very classic type of mechatronics equipment, which integrates technologies from multiple disciplines and has extremely high technical characteristics. It has a wide range of applicability. Taking the automobile manufacturing industry as an example, industrial robots can complete the processing of mechanical components, heat treatment of parts, and welding tasks on work pieces.

While completing these anthropomorphic operations, the robot can also repeat Programming to automatically control tasks. After industrial robots are put into production tasks, the quality of the products has become more stable, and the production capacity has also been greatly improved. It can also be very competent for tasks under harsh working conditions. The birth of robotics technology has undoubtedly brought about a radical change in the manufacturing and processing industry. For now, the appearance of robots has brought the most obvious changes to the manufacturing and processing industry. Among many processing tasks, robots are used to Substituting ordinary workers for operations has become a development trend, which is also caused by the limitation of human body conditions by many factors [2].

In order to ensure the personal safety of workers in the production and processing of products, arc welding and painting More harsh and high-intensity tasks such as handling, handling, etc. have been gradually replaced by industrial robots. In unmanned factories that use industrial robots, all tasks are implemented by computer-controlled robots, CNC machine tools, unmanned transportation vehicles and automated warehouses. Manpower no longer participates in the direct production of the workplace. The role of the worker has also changed, from a front-line operator to a commander [3]. The trial operation of the unmanned factory has also achieved obvious results, and it needs to be close to before the change. Compared with the processing and manufacturing tasks that hundreds of skilled operators took half a month to complete, now it only takes four ordinary workers to complete it in only one day.

With the development of intelligent robot technology and artificial intelligence theory, it has become an inevitable trend to realize the intelligence, generalization and flexibility of welding product manufacturing. At present, welding robots are widely used in various fields. Different welds require different trajectories to plan. For a long time, many people have devoted themselves to the research of trajectory planning and inverse solutions of robots. However, the inverse kinematics of welding robots is relatively cumbersome, and no satisfactory solution has been found. Based on this situation, in order to achieve the For the welding between the stainless steel sheets of the welded seam, this article uses a certain type of industrial stainless steel welding robot under the ABB company as the research object, comprehensively using CAD three-dimensional modeling technology and cam post-processing technology, and the two pipes are orthogonal and butt Take the welding seam as an example, a method of quickly and accurately obtaining the nc code for controlling the movement of the five-axis welding robot is proposed, and the accuracy of the trajectory of the intersecting line is simulated and analyzed by MatLab software.

The rest of the manuscript is organized as the recent work in the field of continuous trajectory planning of Industrial welding robot based on CAD technology is described in Section 2. The structural model of welding robot is described in Section 3. The CAD/CAM modeling including welding process analysis is described in Section 4. The Welding robot trajectory mechanism along with the establishment of welding robot topology is presented in Section 5. The conclusion drawn from the proposed work is described in Section 6.

2 LITERATURE REVIEW

Yahui et al. use the Leap Motion gesture recognition device to obtain the gesture trajectory path, and the median filter and the mean filter are used to de-noising the original path to obtain a smoother original gesture trajectory. When the industrial robot is required to run the trajectory repeatedly and efficiently, the gesture trajectory is planned with respect to the joint space, and a certain number of key points are selected according to the need. The results show that the optimized particle swarm optimization has the advantages of fast convergence speed and good optimization effect, and the particle swarm optimization algorithm is used to optimize the gesture trajectory [4].

In order to achieve smooth interpolation of robot end-effector, Niu et al. proposed a new algorithm based on unit quaternion spline curve. This algorithm combines spherical linear quaternion interpolation and cubic B-spline quaternion curve. By using this method, a continuous smooth trajectory with multiple teaching directions is obtained. Results The curvature analysis of an example shows that the directional trajectory constructed by the algorithm satisfies C2-continuity. The algorithm satisfies the requirement of multi-directional smooth interpolation for robots in industrial applications [5]. Ying et al. took the REBOT-V-6R robot of Shenzhen Yuanchuangxing Technology Co., Ltd as the research object, established the 6-degree-of-freedom simulation interface with Matlab, and planned a rectangular trajectory on the end of the robot with cubic polynomial on the simulation interface. The motion curves of 6 joints of the robot are obtained. On this basis, a 6-DOF robot trajectory interpolation algorithm based on DMC open motion control system is proposed, and the implementation of rectangular trajectory on DMC is introduced. The experimental results show that this method can reliably and accurately realize the trajectory movement of the robot [6].

The product models constructed by the original CAD system are all simple combinations of collective pixels (points, lines, circles, etc.). It is difficult to modify the model and generate new designs. Parametric design methods are an effective way to solve this problem [7]. From the perspective of the application of parametric technology in mechanical product design, the development process of parametric technology has roughly gone through the following five stages: two-dimensional CAD stand-alone work; solid modeling technology and three-dimensional system development; parameterization and variable technology; product information Model PDM/ERP integration; integrated development system based on product development platform [8, 9]. In recent years, the secondary development of CAD based on the product platform has been widely used in the field of machinery manufacturing at home and abroad.

Kim et al. proposed a modeling method rule to adjust the mapping relationship between geometry and functionality, form the best layout of the product family, and obtain the core platform of the product [10]. Sinha et al. create a kind of quantitatively describe the core platform of the relationship between product diversity and parts sharing [11]. Matros et al. proposed a design idea of variable parameter platform [12]. May et al. established the core structure of serialized products based on reasoning rules and graphical representation methods [13]. Many domestic scholars have also carried out related research. For example, Jayanti et al. established a product modular family method based on structural design matrix [14]. Camba et al. adopted a product platform method based on similar functions. It can be seen from the survey that the goal of parametric technology development is to develop an open and extensible design platform, so as to realize the rapid and intelligent design of corresponding products [15].

3 WELDING ROBOT STRUCTURE MODEL

The welding robot realizes the translation and rotation movement in the Cartesian coordinate system according to the RMRM (rotation-movement-rotation mechanism), in which the two rotating shafts rotate around the x-axis and the z-axis respectively to realize the swing of the welding gun and the work piece Rotational motion. This model conforms to the five-axis allocation method of a five-axis machine tool. Theoretically, it can be welded at any position in space and at

any posture, and it is convenient to use cam software to plan the welding trajectory. The established welding robot structure model is shown in the figure 1.

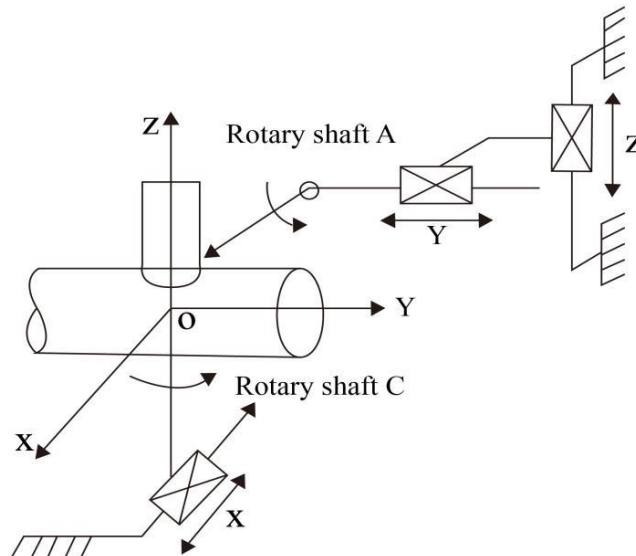


Figure 1: Structural model of welding robot.

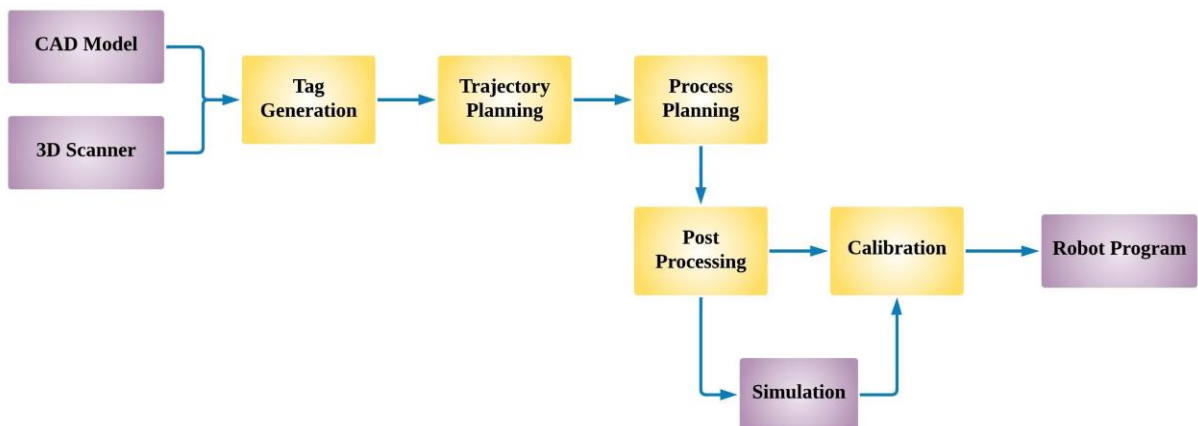


Figure 2: Block diagram of the proposed industrial welding robot system.

Figure 2 presents the block diagram of the proposed industrial welding robot system. The main working of the proposed system is categorized in six steps where first step is the computer model generation which is generated during the initial stages of design of a product. The second stages the tag generation where the initial and the end points of the process are identified. Third stage is responsible for the trajectory planning where the motion of Robot is planned and chances of collisions are assessed. The fourth stage is a process planning which is responsible for the individual process for optimization and sequence. In the fifth stage the post processing takes place where uh the desired process of input and output is inserted and the overall program is is converted into to the machine language of robot. Final stage is the calibration which is responsible

for the execution of the program. In this stage the difference among the CAD data and real time fabrication is measured.

4 CADD CAM MODELING

With the continuous development of computer technology, the use of Pro/E software for model design and MasterCAM software for CNC machining has become the preferred CADD CAM method of current enterprises.

4.1 Welding Process Analysis

In the welding process parameters, the welding speed, walking angle and working angle of the welding torch are particularly important. The welding speed is determined by the movement speed of the robot end effector. The walking angle and working angle of the welding torch are determined by the robot's welding torch attitude. From the perspective of welding quality control and welding process, the adjustment of process parameters such as welding speed, walking angle and working angle of the welding torch must be realized in the space trajectory planning of the welding robot [16, 17]. The model and its projection on the xoy surface are shown in Figure 3.

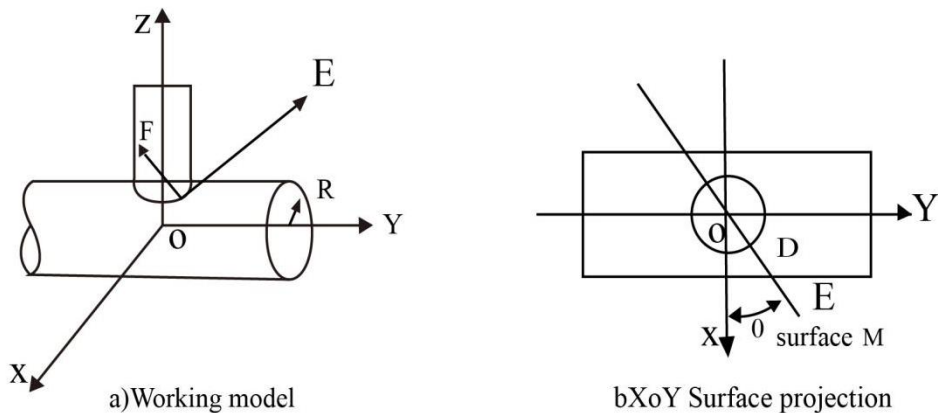


Figure 3: Projection of the work piece model and xoy surface.

Take any point on the weld D and the Z axis as a plane M, the plane M is perpendicular to the XOY plane, and the angle between the plane M and the XOZ plane is θ , and the counterclockwise direction around the Z axis is defined as the positive direction of the θ angle. The polar aiming end is defined as the D end, and the other end is defined as the E end. The entire welding gun is represented by the vector DE. The length of the vector DE is the effective swing length L_t of the rotation axis A, that is, the actual swing distance from the tip of the welding gun to the axis of the rotation axis A. During the welding process, the generatrix of the branch pipe with a radius of r is always parallel to the Z axis, and the main pipe with a radius of R has a unique tangent at any point on the crossing line, and one of the tangent planes is with the crossing line. The straight line perpendicular to the tangent to this point is called the main pipe tangent [18, 19]. In order to ensure that the welding gun axis is always flat at the angle between the branch pipe bus and the main pipe tangent, the welding gun pose has the following constraints: 1) The D end must be on the intersecting line; 2) The vector DE is located in the plane M corresponding to the point D on the intersecting line; 3) The angle between the bus bar of the flat branch pipe of the vector DE and the tangent line of the main pipe. Set the radius of the branch pipe to r and the radius of the main pipe to R , then the parameter equation of the intersecting line for:

$$\begin{cases} x = r \cos \theta \\ y = r \sin \theta \\ z = \sqrt{R^2 - r^2 \cos^2 \theta} \end{cases} \quad (1)$$

In the formula: the value range of θ is $0^\circ \sim 360^\circ$, when $\theta = 0^\circ$, the surface M overlaps the XOZ surface, and the intersection point of the intersection line and the XOZ surface at $x < 0$ is the intersection line $x = -$. The point of r is the starting point.

Calculate the parametric equation of the e-end trajectory of the welding gun from equation (1):

$$\begin{cases} x = L_t \sin \beta \sin \theta + r \cos \theta \\ y = L_t \sin \beta \cos \theta + r \sin \theta \\ z = L_t \cos \beta + \sqrt{R^2 - r^2 \cos^2 \theta} \end{cases} \quad (2)$$

among them:

$$\begin{cases} \beta(\theta) = 0.5 \arccos TB & \theta \in [0, 0.5\pi) \cup [1.5\pi, 2\pi) \\ \beta(\theta) = 0.5\pi - 0.5 \arccos(-TB) & \theta \in [0.5\pi, 1.5\pi) \\ TB = -r \cos^2 \theta / \sqrt{R^2 - r^2 \sin^2 \theta \cos^2 \theta} \end{cases}$$

In the formula: θ is a parameter variable; β is a function of θ , which represents half of the angle between the branch pipe bus and the main pipe tangent.

4.2 CAD Design based on ProoE

After the two-pipe surface model is established with ProoE software, an auxiliary surface is established, and the auxiliary surface is perpendicular to the welding gun axis at any point D. As shown in Figure 2, the vector DF and the vector DE are perpendicular to each other at the point D and are located on the surface M, Then the point F parameter equation is:

$$\begin{cases} x = r \cos \theta + k \cos \theta \\ y = r \sin \theta + k \sin \theta \\ z = \sqrt{R^2 - r^2 \cos^2 \theta} - k \tan \beta \end{cases} \quad (3)$$

In the formula: k is the proportional coefficient. The curve cluster of point F is obtained from formula (3), and the auxiliary surface is established by using boundary blending.

4.3 Generate Welding Path based on MasterCAM

Export the IGES file from the ProoE software and import it into the MasterCA software, set the work piece coordinate system according to Figure 2, and determine that the work piece origin is at the intersection of the two pipe axes [20]. Select the five-axis curve processing method, and according to the relevant process parameters, in the MasterCAM software Set relevant processing parameters in the.

1) Select the welding intersecting line as the 3d space welding curve. This article sets the lowest point of the intersecting line as the arc ignition point and the arc extinguishing point that is, welding from the arc ignition point to the upper left bus bar of the circular tube with radius r . Then

continue welding from the upper left bus bar to the upper right bus bar of the circular tube with a radius of r , and then return to the arc ignition point from the upper right bus bar, and finally the arc is extinguished to stop welding, so as to obtain a high-quality weld.

2) In the curve streamline control, set the distance of each step of the welding gun d end to control the density of the generated motion track points.

3) Set the tool axial control with the auxiliary curved surface made in the ProoE software, so that the welding gun always meets its pose constraints when welding along the weld.

4) In the parameter setting of the advance and retreat tool, enter and exit the intersecting line weld with the posture of the arc ignition point and the arc extinguishing point to ensure the arc ignition and arc closing process of the welding. After the processing parameter setting is completed, the welding gun moves. The simulation is shown in Figure 4.



Figure 4: Simulation of welding gun movement(a) Beginning stage (b) Ending stage.

4.4 Machine Tool Characteristic File of Customized Welding Robot System

In MasterCAM software, machine tool characteristic files include machine tool unit modules, components and controller definition files, as well as special post-processing files. This article mainly introduces customized special post-processing files. Use the five-axis post-processing program template provided by MasterCAM software to target. The developed welding robot customized special post-processing program. The post-processing process is mainly to convert the data of the welding trajectory into the motion parameters of each axis of the welding robot. For the structural characteristics of the welding robot, it mainly deals with the post-processing machine tool characteristics file (PST file). To modify the 4 parts, and the specific post-processing parameter settings are shown in Table 1.

<i>Code type</i>	<i>code</i>	<i>Comment</i>
Rotary axis address allocation code	str_pri_axis"C"	The rotation axis c is the first rotation axis
	str_sec_axis"A"	The rotation axis a is the second rotation axis
Machine type setting	mtype:1	Rotation mode of welding torch swing worktable

Rotation axis vector plane code	rotaxis1\$=vecy	The rotation axis c rotates the zero position in the negative direction of the y axis
	rotdir1\$=vecx	The direction of rotation of the rotation axis c is positive to +x
	rotaxis2\$=vecz	Rotation axis a rotates the zero position in the positive direction of the z axis
	rotdir2\$=vecy	Rotation axis a rotates in the positive direction of -y
Rotating shaft pendulum length (mm) setting use_tlength:0	toollength:15	The effective swing length of the welding gun is 15 mm

Table 1: Post-processing parameter settings.

In Table 1, the effective pendulum length of the welding gun refers to the distance between the intersection of the axis of the rotating shaft a and the axis of the welding gun to the tungsten electrode aiming end of the welding gun.

5 WELDING ROBOT TRAJECTORY PLANNING

5.1 Establishment of Welding Robot Topology

The welding robot forms a typical unbranched open-loop multi-body system from the welding torch to the work piece. The work piece coordinate system is selected as the reference coordinate system, and the work piece is 0-body, which is numbered according to the sequence of joint series. The cxzya topology of the five-axis welding robot as shown in Figure 5.

According to the current jb3051-99 "Nomenclature of Coordinates and Movement Directions of CNC Machine Tools", the right-handed Cartesian coordinate system fixed to each body of the multi-body system is stipulated. The coordinate system of each body is a sub-coordinate system, and each sub-coordinate. The coordinate axes of the system are parallel. According to the specific structure of the welding robot, the axis of the rotation axis a is parallel to the x axis, and the axis of the rotation axis c is parallel to the z axis. The x axis, y axis and z axis sub-coordinate system are all set in the axis of the shaft, the plane passing through the torch axis and perpendicular to the axis of the a-axis is unique. The intersection of the a-axis axis and the plane is selected as the origin of the a-axis sub-coordinate system; the c-axis and x-axis sub-coordinate systems are set on the c-axis axis. The origin coincides with the origin of the work piece coordinate system; the origin of the welding torch coordinate system is at the tungsten aiming end of the welding torch; the coordinate axis orientation of each sub-coordinate system is the same in the initial state.

5.2 Kinematics Modeling of Welding Robot

The kinematic modeling process of the five-axis welding robot is based on the coordinate Pt of the tungsten aiming end of the known welding gun (homogeneous coordinates are generally (0,0,0,1))

T and the vector coordinate U_t of the welding torch axis (the homogeneous coordinates are generally $(0,0,1,0)$ T, establish the relationship between the movement of each axis and the coordinates P_w and U_w of P_t and U_t in the workpiece coordinate system:

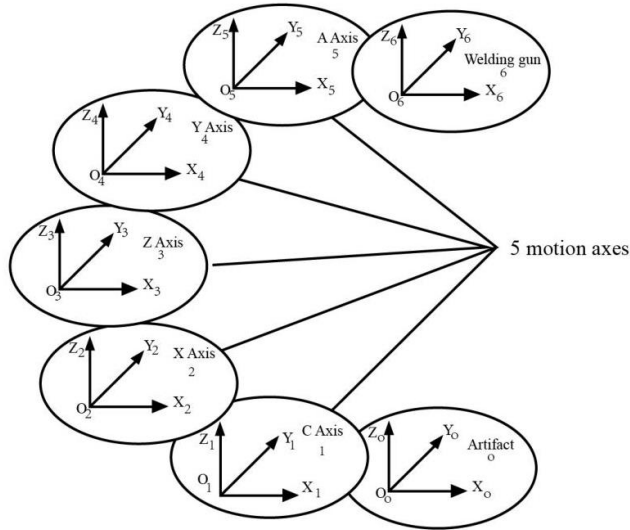


Figure 5: Topological structure of welding robot.

$$P_w = T_{01} \bullet T_{12} \bullet T_{23} \bullet T_{34} \bullet T_{45} \bullet T_{56} \bullet P_t$$

$$U_w = T_{01} \bullet T_{12} \bullet T_{23} \bullet T_{34} \bullet T_{45} \bullet U_t$$

$$P_w = \begin{bmatrix} \cos C & \sin C & 0 & 0 \\ -\sin C & \cos C & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos A & -\sin A & 0 \\ 0 & \sin A & \cos A & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ -L_t \\ 1 \end{bmatrix} \quad (4)$$

$$U_w = \begin{bmatrix} \cos C & \sin C & 0 & 0 \\ -\sin C & \cos C & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos A & -\sin A & 0 \\ 0 & \sin A & \cos A & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ -L_t \\ 1 \end{bmatrix} \quad (5)$$

Where: T is the homogeneous transformation matrix; $(0,0,-L_t)$ is the coordinate value of the origin of the welding gun coordinate system in the A-axis coordinate system; dx , dy , and dz are the three translational axes along their respective The commanded movement amount of the X, Y, and Z axis translation of the coordinate system; A and C are the commanded rotation amount of the two rotation axes around the X and Z axes of the respective coordinate system.

5.3 Simulation Verification

This paper uses MATLAB software as a platform to simulate and analyze the welding track and welding gun posture. Use formula (4) and formula (5) to establish a matrix equation, take $r=15\text{mm}$, $R=25\text{mm}$, $L(84)=15\text{mm}$, according to NC code data Obtain the welding trajectory, as shown in Figure 6.

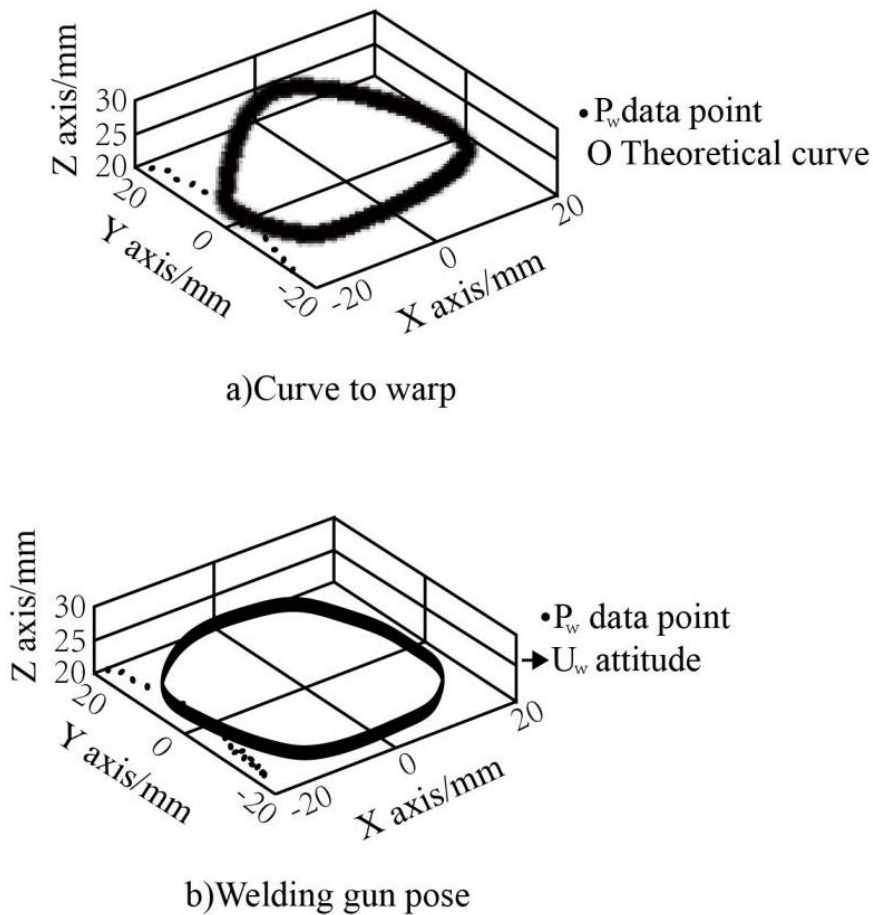


Figure 6: Welding track.

According to the NC code data, use the data sampling interpolation processing method to perform coordinate projection processing on the interpolated multi-dimensional space curve, and divide the coordinate increments in linear proportions to find each interpolation period. The micro-increment value, speed and acceleration of each joint. Let the welding gun weld at a constant speed of

5mmms from the arc ignition point, and the motion speed and acceleration curve of each joint is shown in Figure 7.

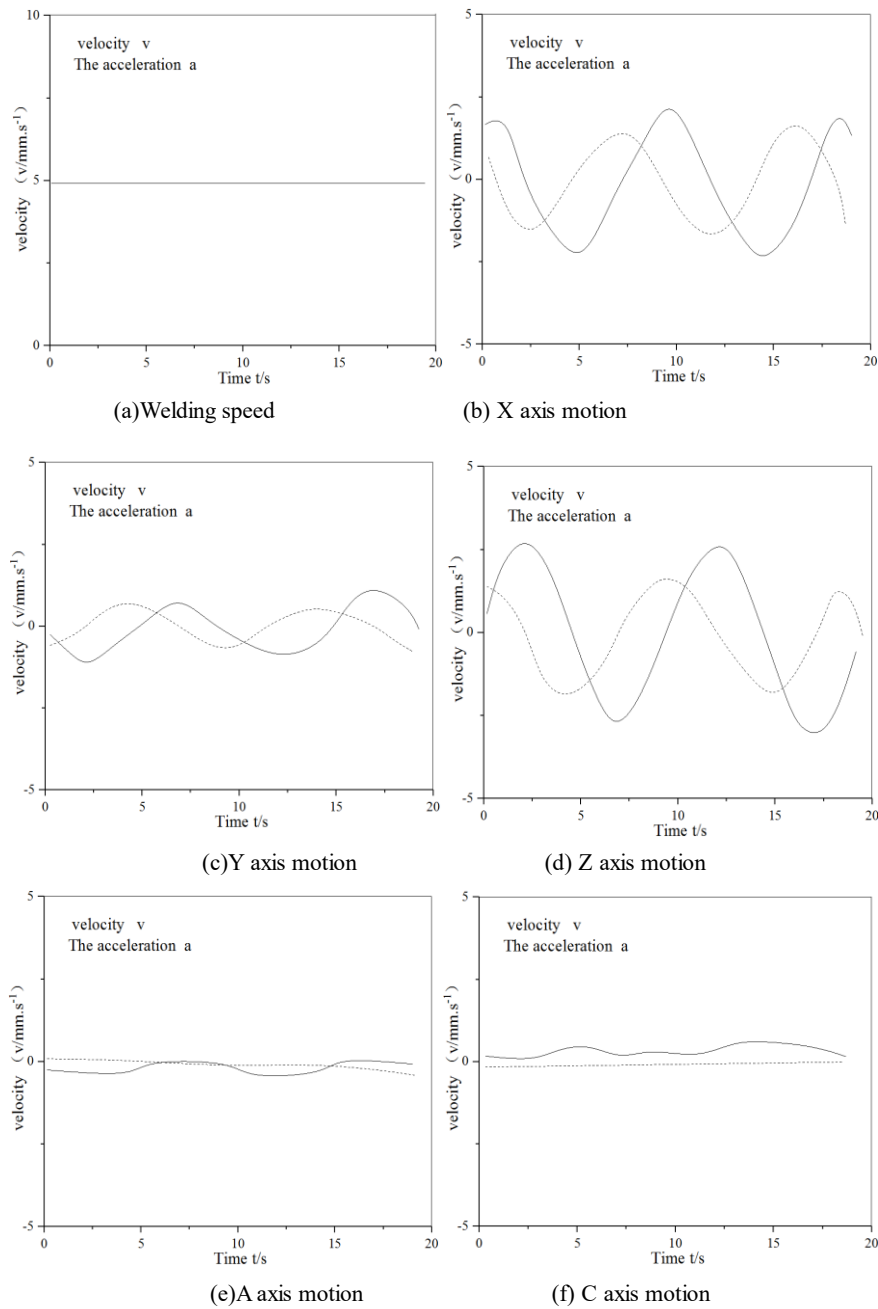


Figure 7: Speed and acceleration curve of each joint.

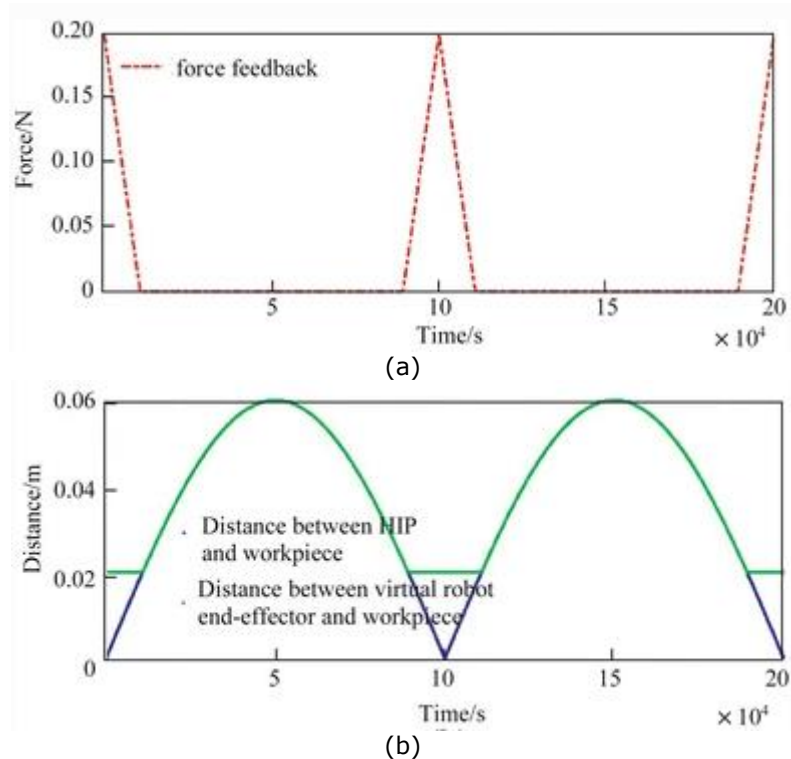


Figure 8: Feedback profile of desired offset distance in surface D.

Figure 8 depicts the relationship between the feedback force and distance among the work piece. From the observation when the value of surface D is 0.03 m. When there exists no point in the sphere of radius R, in this case no force feedback is applied which leads to the result that there is no suitable point for determining a welding path. On the other hand when the product is brought closer to the surface of work piece, claiming that distance is lesser than surface value D, the isosurface is computed. The validation of the proposed system please tested with 5 users that offers small sample size. The experimental results presents that the visual interface of the proposed system improve the accuracy of welding part in comparison with the complete visual interface. It is also observed from the experimentation that the user experience is enhanced in the definition of robot welding path on remote basis. The proposed system presents promising results for the application of remote welding programming.

6 CONCLUSION

This article comprehensively uses cad three-dimensional modeling technology and cam post-processing technology to propose a trajectory planning method based on CADD CAM technology, which realizes the curve interpolation calculation of welding trajectory and welding gun pose. Comparing theoretical analysis and simulation results, it can be seen that the welding robot moves according to the predetermined trajectory of the design, and the robot movement is continuous and stable, and the movement performance is good. There is no sudden change in the linear velocity, angular velocity, linear acceleration, and angular acceleration of each joint, indicating the movement process Stable, no violent shaking phenomenon, can ensure the quality of the weld. The method described in the article provides a theoretical basis for realizing the trajectory planning of different types of intersecting line welds, and the reliability of the method discussed is proved through welding experiments.

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