Robot Welding Path Planning and Application Based on Graphical Computing

Jingjing Lou, Xujiang Yu, Yongfei Chen, Zhubing Sun, and Pengfei Zheng

Abstract As a classic problem in artificial intelligence research, robot welding path planning has been extensively studied. Related scholars have also proposed many solutions, such as heuristic algorithm, neural network, genetic simulated annealing algorithm, improved genetic algorithm. But there are still deficiencies in welding torch posture, welding position, and robot motion stability. Because of the characteristics of the welding seam have a vital influence on the path planning of the welding robot, it is also the basis for ensuring the welding accuracy. From the perspective of graphic calculation, the graphical computing method of precise welds is analyzed, the point cloud graphics of the welded parts are used to calculate the overlap of primitives, and the accurate and rapid extraction of weld features are realized by changing the graphic representation of the welded parts model. According to the connection characteristics of the weldment, the characteristics of the weldment are collected, and a simple, fast, and more versatile method for extracting and calculating weld features is designed, and the weld features are discretized. Discrete weld feature points are used as the basis for path planning of the welding robot to carry out reasonable welding path planning, which reduces the manual teaching process and workload. Finally, a robot welding path planning method based on graphical computing is proposed, and corresponding simulation experiments are carried out.

Keywords Graphical computing · Point cloud · Welding robot · Path planning

1 Introduction

Welding is an indispensable surface forming technique in modern industrial high quality and efficient manufacturing technology. It is a method of bonding workpieces by heat or pressure or both, and with or without filler material. In essence, it is a

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processing method in which metal atoms on two separated solid surfaces are brought close to the lattice distance (0.3–0.5 mm) by a suitable physicochemical process to form a metal bond, thus achieving a permanent connection. Its advantages include easy forming, low production cost, adaptability, material saving, high structural strength, good sealing, and easy automation, especially in auto body processing, the use of industrial robots for automatic welding of body is the most typical application.

In welding production, there are many types of components, variable types of welds and complex spatial distribution, and these characteristics make it much more difficult to automate welding using robots. In robotic welding technology, the proper planning of the welding path is crucial. Welding path planning, as a classical problem in artificial intelligence research, has been extensively studied by many scholars and corresponding planning algorithms have been proposed, such as artificial potential field method, genetic algorithm, simulated annealing algorithm [1–8]. In addition, the use of manual instruction for welding path planning is also more common, but the manual instruction method is time-consuming and the accuracy is difficult to guarantee. Therefore, a graphical computing-based robot welding path planning method is proposed in this paper from a graphical perspective and simulated in the RobotStudio environment. Finally, based on the simulation, the OTC FD-B6 welding robot is used for the corresponding example welding test, and the test verifies the effectiveness of the method for robot welding path planning.

2 Graphical Representation of Welding Problems

In general, the welding process of any component can be abstracted as a number of three-dimensional graphics connection problem, the weld is the spatial intersection of these three-dimensional graphics. As shown in Fig. 1, where (a) is the welding model of a tee pipe; (b) is the welding assembly diagram of a complex box. It is obvious that the welds are all intersecting curves of each component in the assembly

(a) Welding diagram of tee pipe (b) Welding assembly diagram of complex box

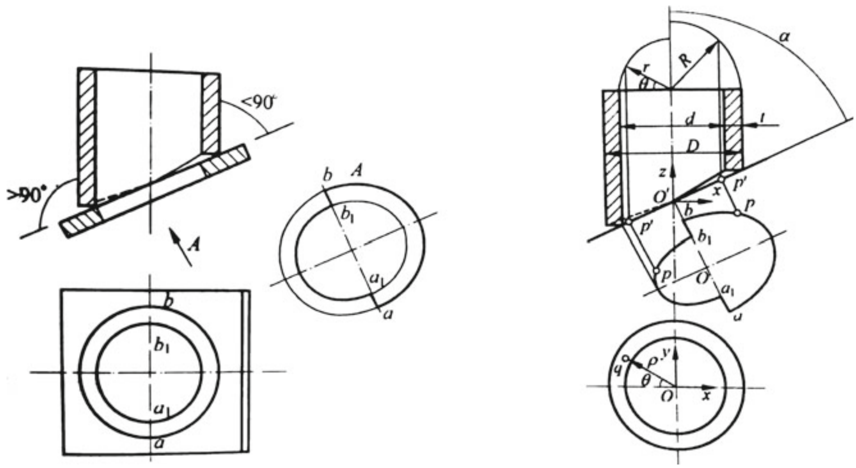
Fig. 1 Weld seam characteristics in welded assemblies attitude. Therefore, the problem of calculating the weld curve is essentially a graphical problem, and the graphical calculation can be used to find the exact weld curve. In welding robot path planning, the teaching method is based on curve fitting of several manually collected feature points to obtain the welding trajectory curve. Obviously, the more feature points collected, the more accurate and time-consuming the welding trajectory curve is. Based on this need, a discrete representation of the weld profile is used to plan the weld path.

3 Graphical Calculation Method of the Weld Path

3.1 Parametric Calculation Method of the Weld Curve

3.1.1 Establishment of the Geometric Model of the Weld Curve

The process of building the geometric model is illustrated by taking the example of a cylindrical tube docked with a flat plate. As shown in Fig. 2, the projection of the cylindrical tube and the flat panel buttress is shown, and the full section of the cylindrical tube is performed. As can be seen from the figure, the left half of the cylindrical tube has the inner skin in contact with the surface of the flat plate, and the right half has the outer skin in contact with the surface of the flat plate. At the plain lines aa_1 and bb_1 of the interface surface, the inner and outer skins of the cylindrical tube are in contact with the flat surface at the same time.



(a) Cylindrical tube butted against a flat plate (b) Geometric intersection diagram

Fig. 2 Mathematical model of the docking of cylindrical tube and flat plate

3.1.2 Establishment of Mathematical Model of Weld Curve

The mathematical model for solving the docking of a cylindrical tube to a flat plate is shown in Fig. 2. The dimensions of the structure are known to be D, t and a, $d = D - 2t$, $r = \frac{d}{2}$, $R = \frac{D}{2} = r + t$. Taking any point p, on the interface curve, it can be seen from Fig. 2. That $x_p = -r\cos\theta$, $y_p = r\sin\theta$. Because, $\frac{r\cos\theta}{-z_p} = \tan\alpha$, therefore, $z_p = -\frac{r\cos\theta}{\tan\alpha}$.

Thus, the coordinates of the point on the interface curve are:

$$\begin{cases} x_p = -r\cos\theta \\ y_p = r\sin\theta \\ z_p = -\frac{r\cos\theta}{\tan\alpha} \end{cases} \tag{1}$$

where the values of θ are: $0 \le \theta \le \frac{\pi}{2}$ and $\frac{3\pi}{2} \le \theta \le 2\pi$.

According to Eq. (1), the coordinates of the point p on the epithelial interface curve can be obtained as:

$$\begin{cases} x_p = -R\cos\theta \\ y_p = R\sin\theta \\ z_p = -\frac{R\cos\theta}{\tan\alpha} \end{cases} \tag{2}$$

where the values of θ is: $\frac{\pi}{2} \le \theta \le \frac{3\pi}{2}$.

If Q is any point on the interface surface and ρ is the distance from that point to the axis, for the left half of the interface surface, it have:

$$\begin{cases} x_q = -\rho\cos\theta \\ y_q = \rho\sin\theta \\ z_q = -\frac{\rho\cos\theta}{\tan\alpha} \end{cases} \tag{3}$$

where the values of ρ is: $r \le \rho \le R$, the values of θ is: $0 \le \theta \le \frac{\pi}{2}$ and $\frac{3\pi}{2} \le \theta \le 2\pi$.

Similarly, for the right half of the interface surface, it have:

$$\begin{cases} x_q = -\rho\cos\theta \\ y_q = \rho\sin\theta \\ z_q = -\frac{R\cos\theta}{\tan\alpha} \end{cases} \tag{4}$$

where the values of ρ is: $r \le \rho \le R$, the values of θ is: $\frac{\pi}{2} \le \theta \le \frac{3\pi}{2}$.

3.2 General Calculation Method of Weld Curve

In order to further reduce the computational complexity of the weld curve, a reduced dimensional intersection calculation method of the geometry is proposed. As shown in Fig. 3, the point cloud model of the welded part is collected using 3-D digital scanning technology, and the point cloud data of the intersection area is approximated to find the mean value.

If point P_i of weld 1 and point P_j of weld 2 satisfy $dis(P_i, P_j) \leq \delta$, where δ is the pre-set accuracy value, then the point $P_{c(x,y)} = (P_{i(x,y)} + P_{j(x,y)})/2$ on their intersection curve. These discrete points are the feature points on the weld curve, similar to the manually taught path points. Since these weld curve characteristic points are obtained by graphical calculation method, the number of points is high and the calculation process is simple. In contrast, the graphical calculation method for path planning of the welding robot saves a lot of manual demonstration time and also improves the accuracy of the welding path. A detailed description of this generic calculation method for weld profiles can be found in the literature [9].

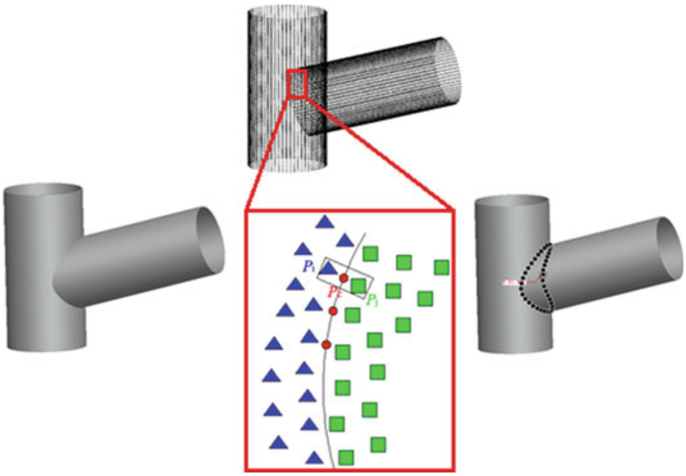


Fig. 3 General calculation model of weld curve

4 Example Verification

4.1 Calculation of the Welding Path for Unequal Diameter Pipes

The following is an example of the unfolding correction calculation for two circular pipes with a spatially curved weld. As shown in Fig. 4, a welding case of two round tubes of unequal diameters, intersecting at a 55° angle. Where, (a) is the 3-D model of the intersection of the fittings; (b) is the actual interface surface of the two fittings obtained by the surface intersection method; (c) is the calculation of the neutral layer curve by the interface surface, and the red bolded curve in the figure is the neutral layer curve.

In order to further verify the effect of the unfolding correction method on the promotion of welding quality, the industrial robot offline programming software RobotStudio is used to simulate and verify the welding path, and the collision detection function in the software is used to monitor the collision of the entire welding process of the robot to ensure that no collision occurs during the entire welding process. Therefore, the above-mentioned welding path can generate the corresponding rapid program, which can be imported into the welding robot control cabinet to be programmed on site.

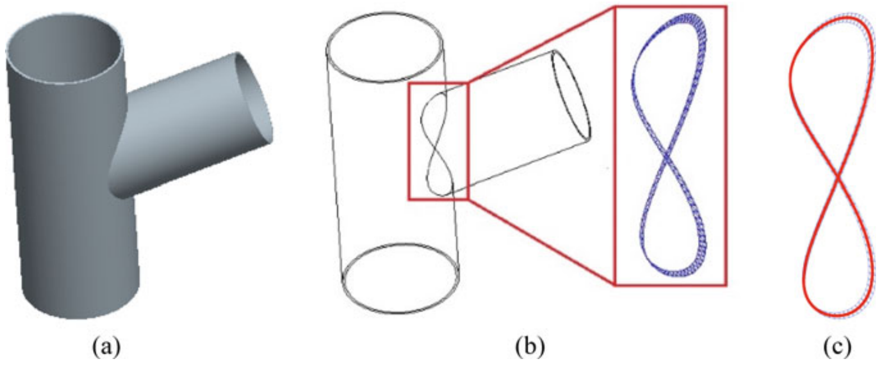


Fig. 4 Arbitrary fillet butt welding of unequal diameter circular pipe parts. **a** Three-dimensional model of the intersection of the tubes. **b** Theoretical intersection curve. **c** Neutral layer intersection curve

(a) Welding robot. (b) Tooling turntable.

Fig. 5 Welding robot welding example

4.2 Weld Test of Unequal Diameter Pipe

In order to more intuitively verify the rationality of the welding path calculation method proposed in this paper, the OTC FD-B6 welding robot is now used to physically weld the unequal diameter pipe weldments in Fig. 4. As shown in Fig. 5, the size of welded parts: the diameter of pipe 1 is 50 mm, the wall thickness is 4 mm; the diameter of pipe 2 is 40 mm, the wall thickness is 4 mm; two pipes fittings are 55° intersecting connection, the joint surface using V-bevel design. The relevant welding parameters are as follows: welding current is 150 A; voltage is 17 V; welding speed is 25 mm/s; welding wire type is ER50−6.

In order to facilitate comparative testing, this example uses two sets of round pipe parts of the same material and size combination, choose the same welding parameters for welding and forming. As shown in Fig. 6, the automatic welding results obtained by using the manual teach-in method for welding path planning can be seen from the two different poses of the tube forming (a) and (b): the residual height of the weld is obvious and the quality of the weld is poor. As shown in Fig. 7, the automatic welding results obtained by using the graphical calculation method for weld path planning can be found from its two different poses (a) and (b): the weld residual height is better and the weld quality is also significantly better than that of the teach-in method.

5 Conclusion

A graphical computational method of the robot welding path planning problem is studied, which abstracts the welding path planning as a surface intersection problem

(a) Attitude 1 (b) Attitude 2

Fig. 6 Example of welding by manual demonstration method

(a) Attitude 1 (b) Attitude 2

Fig. 7 Example of welding by this method

of the welded parts. Using the advantages of the three-dimensional point cloud model, the high-dimensional calculation of complex three-dimensional graphics is simplified to the one-dimensional calculation of geometric elements, which greatly reduces the complexity of the calculation, reduces the time for manual demonstration of the planning path, avoids the chance of random errors easily generated by the manual demonstration method, and improves the accuracy of the welding path calculation. Combined with the industrial robot offline programming software RobotStudio for welding path planning, and the welding of unequal diameter pressure pipes as an example was experimentally verified. The test results show that: the welding process is smooth, no collision phenomenon, good quality weld forming, no weld collapse, weld through, edge biting and other phenomena occur, the proposed welding path calculation method can effectively improve the accuracy of welding forming.

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