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The Study of Intelligent Metal Filling Strategy on Welding Robot Thick Plate Welding

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Abstract: This paper has established the robot model of three-arm and five-degree freedom increasing large scope of traversing welding and given decoupling method of model in “large scope of traversing”, “triangle movement of two arms” and “spherical movement of one arm”. This has completed the image of using geometrical to calculation the inverse problem of kinematics and has eliminated the blind spots of the motions of welding gun of welding robot[1,2]. With 2D function of laser sensor, it realizes the non-contact detection of weld edge, the estimate of the amount of welding metal filling. Then, it gives a intelligent metal filling strategy of 45 degree horizontal butt weld for many times. The result of test works well.

Introduction

Now robots with six-degree freedom structure are widely applied in both domestic and foreign markets, whose critical defect is that the mathematical time speed of the inverse problem of kinematics is slow, has many solutions and singularity. That is to say, welding robots with six-degree freedom structure used in open environment have blind spots and the inverse problem of kinematics nearby the blind spots is not accurate. Therefore, three-arm and six-degree freedom welding robots in the current market can only work in the mode of teaching box. In the process of plate welding, the welding robot often weld with deviation and welding bias phenomena due to strong arc light, high temperature, smoke and workpiece error, clamp accuracy, the workpiece under the influence of thermal deformation and other factors[3,4]. This is the bottlenecks that the current six degrees of freedom welding robot can not be widely used in industry. Two reasons for it, one is the welding robot is fully controlled completely in the open work conditions. the other is the weld can be observed everywhere in the open operation condition.

Robot Structure that can be controlled completely in the open work conditions

As shown in Fig. 1, the welding robot of three-arm and five-degree freedom increasing large scope of traversing is defined in accordance with six Cartesian coordinates{k}[5], $k \in 0 \rightarrow 5$.Apparently when traversing the coordinate of {0} in large scope, only the direction of x_0 is traversed in large scope,so it is enough to let y_1 traverse the welding robot in the opposite direction in the coordinate of {1}. Therefore, it is feasible that only considers the mapping transformation of the three-arm and five-freedom manipulator with the direct problem of kinematics in the welding robot of three-arm and five-degree freedom increasing large scope of traversing.

The attitude of position at the end of the three-arm and five-degree freedom mechanic arm of the welding robot can be described with five independent variables $\lfloor\theta_1 \quad \theta_2 \quad \theta_3 \quad \theta_4 \quad \theta_5\rfloor^T$.

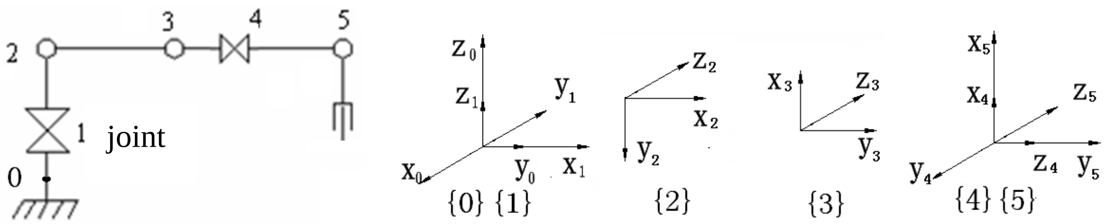

Fig. 1. six Cartesian coordinates for welding robots of three-arm and five-degree freedom plus large scope of traversing

As shown in Fig. 2, when the welding robot traverses in large scope of the traveling mechanism in coordinate of {0} , only the direction of x_0 traverses in large scope. So it is enough to let y_1 traverse in opposite direction the welding robot with relevant length in coordinate of {1}.

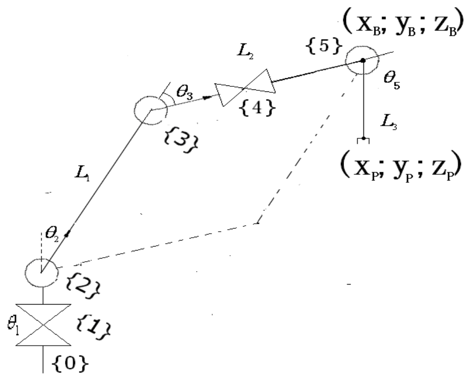

Fig. 2. Coordinate corresponding to attitude of end position of weld

It is assumed that in the Cartesian coordinate of {1}, given the corresponding coordinate {x_p, y_p, z_p}of attitude at one end of the welding robot, at the same time it is required that the trajectory of welding robot keep not shaking during the welding and maintain the welding gun keep perpendicular to the welding surface, then the coordinate {x_B, y_B, z_B} and the coordinate {x_p, y_p, z_p} of the welding point corresponding only traverse with the rod length L_3 in the direction of z_1 in Cartesian coordinate. During the design of the welding robot of three-arm and five-degree freedom increasing large scale of traversing, it makes the joint angle θ_3 larger than 0 through the limit mechanism, that is to say, the three-arm and five-degree freedom mechanic arm of this welding robot will not have the attitude at the welding end related to the dotted line shown in Fig. 2[6,7].

Through above three methods, the attitude of three-arm welding robot corresponding to the expected welding point P can be fixed. As triangular geometrical calculation, there are:

$$\theta_1 = \arg\tan(y_p / x_p).$$

$$\theta_2 = \frac{p}{2} - \arg\tan((z_p + L_3)/\sqrt{x_p^2 + y_p^2}) - \arg\cos\left(\frac{x_p^2 + y_p^2 + (z_p + L_3)^2 + L_1^2 \quad L_2^2}{2L_1\sqrt{x_p^2 + y_p^2 + (z_p + L_3)^2}}\right).$$

$$\theta_3 = p \text{ - arg}\cos(\frac{L_1^{\ 2} + L_2^{\ 2} - x_p^{\ 2} - y_p^{\ 2} - (z_p + L_3)^2}{2L_1L_2}).$$

$$\theta_4 = 0.$$

$$\theta_5 = \pi - \theta_2 - \theta_3. \quad (1)$$

Among which: θ_1, θ_2, θ_3, θ_4, θ_5 are the joint angle of the five-degree freedom mechanical arm respectively. L1 =480 mm, L2 =480 mm, L3 =280 mm are length of three arm rods respectively. According to Fig.2, θ_4=0, although θ_5 is the joint variable, rod arm L3 always keeps parallel to z_1, this attitude of welding gun always remains unchanged in welding, which is equal that the gun is always perpendicular to the welding surface. In the real welding condition, it is not always the welding surface parallel to the surface of $x_1 0_1 y_1$. At this time, it can change θ_4 from -90 degree to +90 degree and align the welding surface. Especially, in the fillet welding, the welding gun should be in the pitch direction and raise a certain angle. At this time, with calculated joint variable of θ_5, which can be reduced by Δ (Δ is from 0 degree to 90 degree). Obviously, it is required that keep Δ and θ_4 unchanged in a welding process to keep the welding gun not shaking.

As shown in Fig. 2: θ_4=0, in the basic of joint variable θ_5, θ_4 is from -90 degree to +90 degree. With the additional joint variable θ_5, the space diagram with θ_5 that is reduced by Δ is shown in Fig. 3. Because of θ_4 and Δ in the corresponding to the range of values, just as the arm move below the hemisphere. So it is called “model of one arm spherical movement”.

Geometrical correspondence of this model is:

$$x_B = x - L_3 \bullet \sin\Delta.$$

$$y_B = y - L_3 \bullet \cos\Delta \bullet \sin\theta_4.$$

$$z_B = z - L_3 \bullet \cos\Delta \bullet con\theta_4. \quad (2)$$

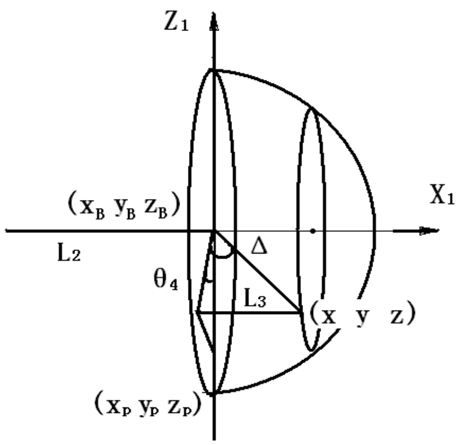

Fig. 3. model of one arm spherical movement

The geometric calculation of Eq. 1 is used to solve the difficult problem of the solution of inverse kinematics for the welding robot of three-arm and five-degree freedom increasing large scope of traversing. Assume that given the end position (x ; y ; z) of a welding robot, according to the geometric calculation of Eq. 1, the joint variable $[\theta_1 \ \ \theta_2 \ \ \theta_3 \ \ \theta_4 \ \ \theta_5]^T$ corresponding to the attitude can be obtain quickly. And it is one to one correspondence. As long as five position servo motors are controlled to the joint variable, the welding gun of welding robot can reach the desired position.

If the welding robot works like a human, it controls the welding gun to make operations like up, down, left, right, stretch in Euclidean three-dimensional space (x，y，z), it is just to make the welding robot in Cartesian coordinate{1}. Based on one end position of wielding robot and through the geometrical calculation of Eq. 2, the joint angel variables of $[\theta_1 \ \ \theta_2 \ \ \theta_3 \ \ \theta_4 \ \ \theta_5]^T$ related to the attitude can be obtained and then this kind of control can fulfill with five position servo motors work together. This kind of “linkage operation” mode is in line with human welding habits.

Intelligent Metal Filling Strategy of Thick Plate Welding

The acquisition of laser array data is completed by a 2D-function sensor, the type of which is LJ-G200. It is manufactured by KEYENCE company. The longitudinal height detection range is 200±48mm. The height resolution is 2μm. The horizontal width detection is 70 mm. The width resolution is 20μm. The Laser spot is linear. One measurement can complete the 3500 points height measurement on the linear spot and the width is divided equally. It can achieve 2D non-contact measurement on the detected object. The sampling frequency is 3.8 ms.

The laser array sensor is fixed on the welding gun of the welding robot with three-arm and five-degree freedom increasing large scope of traversing welding. As shown in Fig. 1, in the Cartesian coordinate of {0} , The longitudinal height of the sensor is taken in the direction of Z_0 and the lateral width is taken in the X_0 direction. We control the posture of the welding robot to maintain a constant height attitude (Z_0 constant). It can walk along the Y_0 at a constant speed and record every 0.5mm. Then it will form the test pairs: (x_i^j, y_i^j, d_i^j), it takes m 0.5mm along the direction of Y_0, i∈{1 to m}, the width j∈{1 to 3500}, d_i^j is the height detection value of the 2D sensor on (i, j).

We will take the horizontal 45 degree butt weld as an example to introduce the intelligent metal filling strategy of thick plate welding. As shown in Fig. 4, it is obvious that the detection height of the 2D sensor is not the height of the weld seam and the width of the weld detection is not the amplitude of the weld seam. So we need to do the following data processing.

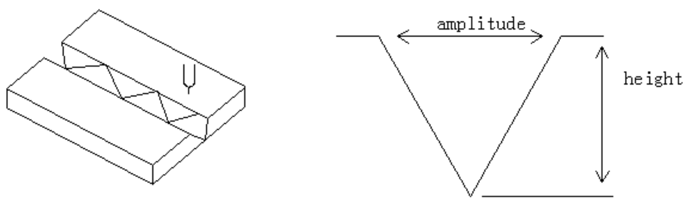

Fig. 4. the horizontal 45 degree butt weld

We use the 2D sensor to detect the value d_i^j at the height of（i, j）and take the absolute of the backward difference at the width j∈{1 to 3500} direction[8,9]. For horizontal 45 degree butt weld bevels, it can form a binary array on the width direction $\left|\partial d_i^{\,j}\right|$. When the absolute of the difference is big, it means this is the area of the weld seam. The data is saved as the name d_i^j, j∈{L_i to H_i}. Among them, L_i is the boundry number of the lower weld, H_i is the boundary number of the upper weld. When the absolute of the difference is small, it means this is the area of the welding plate. the data is useless, it can be deleted. Then we can get the expression of the welding area with Eq. 3.

$$z_i^j = d_i^j - d_i^a/2 - d_i^b/2.$$

$$W_i = (L_i - H_i) \bullet \Delta.$$

$$V = \sum_{i=1}^{m} \sum_{j=1}^{3500} z_i^j \bullet \delta. \tag{3}$$

Among them, Z_i^j is the height of the weld seam. When the value is 0, it means it is outside the borders. d_i^a , d_i^b represent the height of upper and lower weld points of the 2D sensor. W_i is the amplitude of the weld seam. Δ =20μm is the width resolution. V is the filled volume of the thick plate welding metal. δ=2μm is the height resolution. i∈{1 to m}, m is determined by the weld length, width j∈{1 to 3500} .

Intelligent Filling Strategy of Welding Robot and Experimental Data

Take two thick steel plates and process horizontal 45 degree butt weld. Its total length is 298mm. The speed of molten steel out of the welding torch of the welding robot is 1.2g/s. The steel density is 7.9mg/mm^3. With the 2D function of the sensor LJ-G200 non-contact measurement, from Fig. 5, obtaining volume is 14328mm^3.

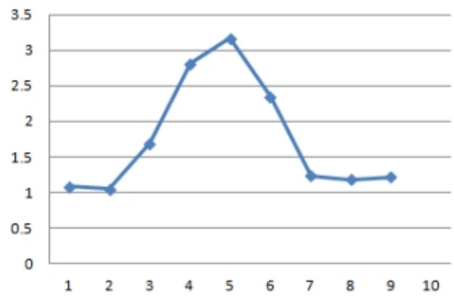

Fig. 5. Measured value line chart

When we weld the thick plate, in order to guarantee the welding strength, we usually need to open 45 degrees' groove butt and the metal filling capacity is very large[10,11]. If we achieve the metal filling for only one time, when the groove high-temperature bath is in the heating and cooling process, it is easy for it to form bubbles and become loose. This will seriously affect the welding quality. So it is usually for the welding robot to take the strategy of multiple metal filling. In this experiment, we fill the weld for five times and the capacity size is 1/25, 3/25, 5/25, 7/25, 9/25 of the volume in turn. The quality required to be filled at each time is 4.5 g, 13.5 g, 22.6 g, 31.7 g, 40.7 g. The time of each welding is 3.8s, 11.3s, 18.8s, 26.4s, 33.9s. The experimental results of an actual welding robot are shown in Table 1:

Table 1. Experimental results of an actual welding robot

Welding test	First filling	Second filling	Third filling	Fourth filling	Fifth filling
Filled volume V	573.12	2292.48	5158.08	9169.92	14328
V error	11.98	23.90	35.82	47.74	59.66
Percent accuracy	2.1%	1.0%	0.69%	0.52%	0.42%

Conclusion

This paper has established the robot model of three-arm and five-degree freedom increasing large scope of traversing welding, which can complete the decoupling of model in “large scope of traversing”, “triangle movement of two arms” and “spherical movement of one arm”. And the inverse problem of kinematics can be solved by using geometric computation for the model of “triangle movement of two arms”. It avoid the multi-solution, improve the calculation speed and eliminate the welding posture blind spot of welding robot. Simultaneously, it solves the difficult problem of the solution of inverse kinematics for the welding robot used at home and broad and achieve the welding robot in line with human welding habits. Though using 2D-function laser array sensor, it can realize the non-contact detection of weld edge and estimate of weld metal filling quantity. The intelligent metal filling strategy of horizontal 45 degree butt welding of thick plate is given. It solves the problems that it is easy to form bubbles and become loose when the mouth of high-temperature bath in the heating and cooling process in one time metal filling.

Acknowledgements

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