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Three Dimension Curve Welding Seam Modeling for Seam Tracking ⋆

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Abstract: A novel modeling method for 3D curve welding seam is presented in this paper based on a welding robot for large workpiece. The 3D curve welding seam tracking is implemented by macro and micro motion which can control translational motion of torch in a large range and implement accurate seam tracking in small range. As such, the self-teaching seam model and real-time seam model are established to accurately control position and orientation of torch. The self-teaching model is obtained by a cubic B-spline interpolation function. Then a continuous position model of a V-type seam is established by using the cubic parameter B-spline least square method. The orientation model of the seam is also established by using the position model and coordinates of seam characteristic points. These three models form the base of macro and micro translational motion control and real-time tracking control. Furthermore, in order to compare the performances of the different position modeling method, simulations have been carried out to produce the modeling results of cubic parameter B-spline least square method and polynomial least square method. The effectiveness of these seam model has been verified.

Keywords: Intelligent robotics; 3D curve seam; Spline least square; Seam modeling and tracking.

1. INTRODUCTION

Robot seam tracking system using visual sensor works in the self-teaching mode and real-time tracking mode. This self-teaching mode autonomously acquires the seam coordinates before welding. Zhou et al.(2006) concluded that the mode overcomes lots of disturbances such as arc glares, welding spatters and smoke, and thus improves the reliability of welding system. However, Wang et al.(2006) commented that this mode is difficult to implement for 3D complex seam systems. In the mode of real-time tracking, welding robots simultaneously learns and tracks the seam [Liu et al.(2006]. The second mode enable welding robot to own some intelligence, which reduces the interference of welder and enhance efficiency. If welding robot can integrate the self-teaching mode with the real-time tracking mode, then the reliability can be strengthened so as to lead an improved the intelligence and efficiency. Indeed, Amin et al.(2003) established seam model by adopting the two modes. Before welding seam trajectory is defined by using visual system, in the welding stage the predefined seam trajectory could be corrected instantly and finally seam tracking could be finished by 4-axes robot.

Though robot welding mode largely affect the performance of seam tracking system, the shape and dimension of seam are also important factors affecting seam tracking quality[Zhou et al.(2005)]. Straight seam tracking has been studied by many researchers, and considerable achievements have been obtained. However, to satisfy the needs of large workpiece welding the system should be able to track curved seams that may change in all the three dimensions. In this context, Zhou et al.(2006a) presented a robotic seam tracking system with a position model and an environment model of the seam that are capable of autonomously acquiring the seam coordinates of the planar butt joint in the robot base frame and planning the optimal camera angle using visual sensor before welding. Zhou et al.(2006b) developed a local model where the direction of planar curve seam was predicted by using the model and then computed the deviation of torch in the x and y axes so as to achieved the final seam tracking. Chen et al.(2006b) and Chen et al.(2006) discussed the realization method of self-teaching, seam modeling, seam tracking in details. Wang et al(2004) established mathematical model of feature points of seam aiming at curve seam and zigzag seam that could harmonize the torch motion and visual servoing tracking. In fact, seam modeling has played an important role in planar straight seam tracking and planar curve seam tracking. The main purpose of planar straight seam modeling is to reduce measurement errors and compute seam deviation. The planar curve seam modeling is still

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used for predicting the direction of seam. Similarly, the 3D curve welding seam model can be used for correcting the TCP in x, y and z axis together with the roll, pitch and yaw angle. Nayak,et al(1993) indicated that the 3D curve welding seam model can be described using cubic parametric polynomial curve function and the cubic parametric curve seam position model can be obtained by using LQ based on coordinates of the seam points. Then pose model can be obtained by employing the position model and other welding seam characteristic point coordinates. However, the model performance was not evaluated and only theoretical conclusions were made which showed that the cubic polynomial least square method was better than the B-spline function model. Mikael(2004) improved the Nayak's seam modeling algorithms and established a 3D curve seam model using quadratic parametric polynomial curve function. This has enhanced efficiency of modeling algorithms and stability of the tracking system, where evaluation was made for the model performance by simulation. However, the simulation only used seam coordinates without noises under the assumption that the tracking errors caused by the noises can be reduced by tracking system without seam model. If the seam model error is big, then the tracking system may not be able to remove the affects of noises, which would lead to the instability of the system.

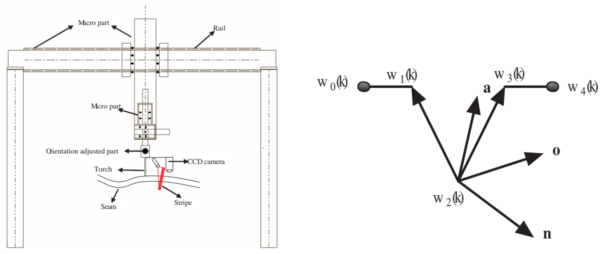
This paper develops the self-teaching model and real-time seam model based on a six degree-of-freedom, nine degree-of-mobility welding robot. The paper is organized as follows. The configuration of the welding robot including its macro part, micro part and visual system is described in Section 2. The role of 3D curve welding seam model is highlighted in Section 3, where the modeling algorithms of V-type seam is also developed. Simulation experiments are described in Section 4 where evaluation and comparison of the performances of modeling algorithm are made. These simulations have verified that these seam modeling method are effective.

2. CONFIGURATION AND FUNCTION OF WELDING ROBOT

A schematic representation of the welding robot configuration is shown in Fig.1(a). The system mainly consists of a macro part, a micro part, an orientation adjusted part and a visual system. For this configuration, the micro part, the orientation adjusted part and the visual system are integrated into the robot handpiece which is mounted onto the end of the frame. The orientation part is mounted on the end of micro part. The macro part is made up of cross rail whose advantage is to enable a large motion range at a low cost. The macro part can realize the large range motion in the X axis, Y axis and Z axis.

2.1 Macro and micro translational motion

The welding system is a nine-axis robot with nine degrees of mobility, six degrees of freedom. Macro and Micro translational motion part possess six degrees of mobility, three degrees of freedom, which are capable of accurately, smoothly adjusting position of torch in a large range. However, macro motion and micro motion interact with each other. As such, one of the key technology of macro and



(a) Schematic representation (b) Visual system

Fig. 1. System configuration of welding robot

micro translational motion is how to harmonize the two motions so as to maintain the continuous smooth motion of torch. The macro part works in the two modes, namely motion planning and motion correction. The purpose of motion correction is to reduce the distance between the origin of the macro coordinate frame and the origin of the micro part coordinate frame. The micro part also works in the two modes, one is the motion under tracking control and the other is again motion correction. In order to assure smoothly motion of torch and seam tracking accuracy, motion correction is carried out by using small steps.

2.2 Self-teaching seam model

In general it is very time consuming to accurately teach complex 3D curve seam, which also depress the welding efficiency. However, simple teaching techniques will overcome above deficiency as the number of sample points used in the curve seam teaching is small. Therefore, the teaching method can be made less time consuming, and is able to obtain the whole characteristics which is very useful to realize welding automation. After the selected teaching points are defined, the fitting of seam can be achieved by either a cubic B-spline or a high-order polynomial. Then the motion trajectory of torch can be planned in the Cartesian space. The planning in the joint space can then be completed by solving inverse kinematics problem. After the teaching of the curve seam, the motion planning of torch can be implemented by using the macro part.

2.3 The components and principle of visual system

As shown in Fig.1(a), the visual system mainly consists of CCD camera, laser and master computer which performs the required image-processing. Since the accuracy is a major concern in this application, the vision sensor moves with the end-effector. The configuration has the camera mounted on the robot's end-effector, which is called as "eye-in-hand" system.

The vision system of the welding robot can obtain the seam features reliably based on the active laser triangulation. At first the seam image is captured by using a CCD camera, and the coordinates of seam characteristic points in the computer plane can be obtained after the seam image is processed. Then the Cartesian coordinates of feature points of the 3D seam can be obtained after the camera and structured light plane are calibrated. Finally the seam coordinate frame can be computed by using the Cartesian coordinates of feature points of the 3D seam. This is a moving coordinate frame defined along the seam, with its origin on the root curve. The y axis of the frame represents the seam direction whilst the z-axis is perpendicular to the seam. The x-axis is determined arbitrarily under the constraint of the right-handed coordinate frame. This coordinate frame is defined in the Base coordinate frame, as is shown in Fig.1(b).

3. THE MODELING OF THE 3D CURVE SEAM

Macro translational motion part is able to adjust position of torch in a large range. Micro motion part are capable of accurately, smoothly adjusting the position and the orientation of welding torch. To set up self-teaching model and realtime seam model is for carrying out the two motion. The self-teaching model can be used for planning motion of the welding robot. The realtime model can be used for the control of position and orientation of torch together with field of view of the camera.

3.1 The function of the 3D curve seam model

To ensure that the seam remains in the Field of View of The CCD camera, in the case of strongly 3D curved seams, the sensor is rotated according to the orientation of the seam. This requires the orientation model of the seam.

The model of the seam is required for four purposes. Firstly, coordinates of root points can be interpolated anywhere along the seam continuously. This feature is particularly important since the structured light image may not be equidistant, while positions of the torch during seam tracking have to be computed at equidistant locations. Secondly, the coordinates of next seam location can be predicted from the seam model. The predicted value may replace the measurement value when visual system is wrong and not able to generate effective coordinates of seam. As such, the visual system have the capability of fault-tolerance, which strengthens the robustness. Thirdly, the seam model can smooth seam data and thus reduce the effects of noises, which is helpful to obtain more accurate seam coordinates. Finally, the seam model including position model and orientation model can be used to adjust the position and orientation of the torch.

3.2 The self-teaching model of the 3D curve seam

The self-teaching model can be set up by using a B-spline function or a polynomial based on the coordinates of coarse teach points. Assuming that the physical seam can be represented by separate curves along the root and other two edges as shown in Fig.2. In the self-teaching model, only the root curve is represented by a sequence of cubic B-spline functions. Since these coordinates of seam are acquired before welding the spatter and the thermal distortion can be avoided, which enhances the reliability of these coordinates. The self-teaching model can be developed by using these coordinates. Indeed, the cubic B-spline function has an excellent local characteristics. In other words,the bad coordinates of seam only affect the local curved welding seam rather than the whole curved welding seam. The cubic B-spline function can be represented in equation (1).

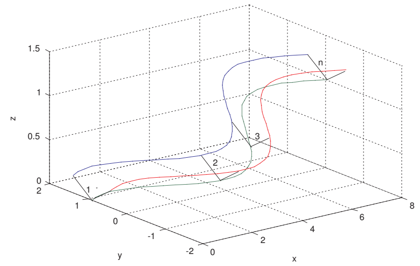


Fig. 2. Three-dimension Seam in the Base Coordinate Frame

$$N_{i,3}(u) = (1/6)\left[\, u^3 \;\; u^2 \;\; u \;\; 1 \,\right] \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \qquad (1)$$

The following equation represents the i^{th} curve welding seam function.

$$C_{i,3}(u) = \sum_{j=1}^{4} N_{j,3}(u) P_{i+j-2} \qquad (2)$$

where variable $u \in [0,1], i = 1, 2, \cdots, n-2]$,$P_{i-1}, P_i$,$P_{i+1}$, P_{i+2} , represents control points coordinates of simply teaching seam, All the $C_{1,3}, C_{2,3}, \cdots, C_{n-2,3}$ represent self-teaching model of the whole welding seam.

The coordinates of simply teaching seam are also called as insert spline point. In order to obtain a cubic spline curve $C_{i,3}(u)$ that go through the insert spline point the control points should be computed firstly. When the cubic spline is used the relationship between insert spline points and control points is as follows.

$$Q_i = (P_{i-1} + 4P_i + P_{i+1})/6 \quad (i = 1, 2, 3, \cdots, n) \qquad (3)$$

where Q_i represents insert spline points, and P_i stands for control points. After two boundary conditions are complemented equation group (3) can be solved. The two boundary conditions may be selected as $P_1 = Q_1, P_n = Q_n$.

3.3 Real-time seam model

The coarse self-teaching model improves the teach efficiency and help to track the whole seam. However, the self-teaching model often suffers from arc light, the thermal distortion, spatters, geometry shape of seam, etc. As a result, a more accurate seam model needs to be established, which is called as the seam real-time model used for the real-time seam tracking. The real-time seam model consists of a continuous position model and a discrete orientation model. The continuous model is a sequence of the cubic B-spline functions. On the other hand, the discrete model is a sequence of seam coordinates frames. Both models are generated from N feature point coordinates in the Base frame. The two models complement each other in computing the required control input.

The position model of the 3D curve seam In the continuous position model of the seam, only the root curve is represented by a sequence of the cubic B-spline functions.

Although the true seam can be described by separate curves along the root and the other two edges, the curve along the root adequately represents the seam position model. Therefore, there is no need to represent the other two curves along the edges of the seam [Nayak,et al(1993)].

The choice of the approach for modeling should be based on the fact that the coordinates of the seam generated is subjected to errors. It is possible to construct either a least square polynomial or a least square cubic spline which fits these coordinates. The two methods both tend to smooth the data. In the paper the least square cubic spline method is adopted. However, in the simulation, the performances of the two method are compared. The position model is represented by a sequence of cubic spline functions. A smooth 3D curve welding seam can be obtained by using the spline function, which helps to stabilize the control process. Assume that $w_2(k)$ represent the root feature points of the seam. During welding, visual system lies in the front of the torch, which can gain close sample points, then corresponding Cartesian coordinates of the seam can be computed. Using these Cartesian coordinates all the local position models are immediately set up, which constitute the whole position model of the seam. The real-time seam model is established by using the accumulated-chord-based parametric cubic spline least square method, where the base function of cubic spline is defined firstly as follows

$$N_{i,d}(u) = \frac{(u-t_i)\,N_{i,d-1}(u)}{t_{i+d}-t_i} + \frac{(t_{i+d+1}-u)\,N_{i+1,d-1}(u)}{t_{i+d+1}-t_{i+1}} \quad (4)$$

where, $t_d \le u < t_{n+1}, 1 \le d \le 3$,t_i represents knots value, $N_{i,0}(u) = \begin{cases} 1, & t_i \le u < t_{i+1} \\ 0 & others \end{cases}$, $a = (x_0^2 + y_0^2 + z_0^2)^{\frac{1}{2}}$,$l_j = ((x_j - x_{j-1})^2 + (y_j - y_{j-1})^2 + (z_j - z_{j-1})^2)^{\frac{1}{2}}$,$j = 1, 2, \cdots, N+1$. The interval of partition is given by

$$\Delta : a = t_0 < t_1 < \cdots < t_{N+1} = b \quad (5)$$

where,$t_j = a + \sum_{i=1}^{j} l_i, j = 1, 2, \cdots, N+1$. In the knots, the following cubic spline functions hold

$$s(p; t_j) = p_j, j = 0, 1, 2, \cdots, N+1 \quad (6)$$

After equation (6) is obtained, each element sequences of coordinate vector of insert spline points can be processed as common spline. When the coordinates of insert spline points is sufficient to accurate a smooth cubic spline, interpolation curve can be obtained directly using equation (4). However, during welding the real-time seam model is subjected to lots of noises, leading to noisy measurement coordinates of insert spline points. This means that it is not suitable to build up the real-time seam model using interpolation spline method. The method that enables to smooth the noises should be adopted. The parameter B-spline least square is such a method. To obtain the cubic B-spline curve about partition (5), knots sequence about partition (5) should be obtained at first.

$$\begin{array}{l} \tau_0 \le \tau_1 \le \cdots \le \tau_k = a < \tau_{k+1} < \cdots \tau_{k+N} \\ < b = \tau_{k+N+1} \le \tau_{k+N+2} \le \cdots \le \tau_{k+N+k+1} \end{array} \quad (7)$$

where,$\tau_{k+j} = t_j (j = 1, 2, \cdots, N)$ and$k = 3$. The cubic B-spline space about partition (5) can be given by $S_k(\Delta) = span\{N_{0,k}(u), N_{1,k}(u), \cdots, N_{n,k}(u)\}$. Let$s_k^*(u) = \sum_{j=0}^{n} \alpha_j N_{j,k}(u)$ be an optimal approximation to equation $s(p, t_j) = p_j$, then we have

$$(s_k^*(u) - PN_{i,k}) = 0, \quad i = 1, 2, \cdots, n \quad (8)$$

where,$P = (x_1, x_2, \cdots, x_m)$,$P = (y_1, y_2, \cdots, y_m)$,$P = (y_1, y_2, \cdots, y_m)$,$s_k^*(u) = (s_x^*(u), s_y^*(u), s_z^*(u))$, and $\alpha_j = (\gamma_{x,j}, \gamma_{y,j}, \gamma_{z,j})$, Substituting $s_z^*(u)$ to equation (8), it can be seen that

$$\left(\sum_{j=0}^{n} \alpha_j N_{j,k}(u) - PN_{i,k}(u) \right) = 0, \quad i = 1, 2, \cdots, n \quad (9)$$

Theorem If there exists a partition $0 \le j_0 < j_1 < \cdots < j_n \le m$, then the sufficient and necessary condition that equation group (9) has a unique solution is given by

$$\tau_i < t_{j_i} < \tau_{i+k+1}, \quad i = 0, 1, \cdots, n \quad (10)$$

Denote $A = (B_j(t_i))_{i=1}^{m}{}_{j=0}^{n}$, then it can be obtained that

$$A^T A \gamma_x = A^T P_x, A^T A \gamma_y = A^T P_y, A^T A \gamma_z = A^T P_z \quad (11)$$

If the condition (10) is satisfied, then (11) have a unique solution $\alpha_i = (\gamma_{x,i}, \gamma_{y,i}, \gamma_{z,i}), i = 0, 1, \cdots, N+k$. As a result, the local B-spline curve $s_k^*(u)$ is obtained. The whole seam curve can then be established by connecting a series of local seam model.

The orientation model of the 3D curve seam The orientation model of the 3D curve welding seam is represented as a sequence of seam coordinates frames $[C(1), C(2), \cdots, C(k)]$. The orientation model is used to compute the orientation of the torch at any point along the seam. In order to compute the seam coordinate frame from the Cartesian coordinates of the five V-type seam feature points, the following method can be used.

Let $\{w_0(k), w_1(k), w_2(k), w_3(k), w_4(k)\}$ be the Cartesian coordinates of the five V-type seam feature points as is shown in Fig.1(b), where $w_0(k) and w_4(k)$ are the edge points of the seam and $w_2(k)$ is the root point. Let the k^{th} seam coordinate frame be given by the following homogenous transformation matrix[Nayak,et al(1993)].

$$C(k) = \begin{bmatrix} n_x(k) & o_x(k) & a_x(k) & p_x(k) \\ n_y(k) & o_y(k) & a_y(k) & p_y(k) \\ n_z(k) & o_z(k) & a_z(k) & p_z(k) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $n(k), o(k), p(k)$ is unite vector along the x,y, and z direction of the k^{th} seam coordinate frame in the Cartesian frame respectively. The above four vectors of the seam coordinate frame are computed from the feature points $\{w_0(k), w_2(k), w_4(k)\}$.

Computation of the origin $p(k)$: $p(k)$ is described by the coordinates of the root feature point of the seam to give

$$p(k) = [w_{2x}(k), w_{2y}(k), w_{2z}(k), 1] \quad (12)$$

Computation of the orientation vector $o(k)$: The unit vector $o(k)$ represents the seam direction and is described by slope vector along realtime model at $u = t_j$. From equation (11), three equation is given by

$$s_x^*(u) = \sum_{j=0}^{n} \gamma_{x,j} N_{j,k}(u), s_y^*(u) = \sum_{j=0}^{n} \gamma_{y,j} N_{j,k}(u)$$
$$s_z^*(u) = \sum_{j=0}^{n} \gamma_{z,j} N_{j,k}(u)$$

Corresponding first derivation are as follows

$$s_x^{*'}(u) = k \sum_{j=1}^{n} \gamma_{x,j}^{(1)} N_{j,k-1}(u), s_y^{*'}(u) = k \sum_{j=1}^{n} \gamma_{y,j}^{(1)} N_{j,k-1}(u),$$
$$s_z^{*'}(u) = k \sum_{j=1}^{n} \gamma_{z,j}^{(1)} N_{j,k-1}(u), \gamma_{,j}^{(1)} = \frac{\gamma_{,j} - \gamma_{,j-1}}{t_{j+n} - t_j}$$

The orientation vector is given by

$$o(k) = \frac{(s_x^{*'}, s_y^{*'}, s_z^{*'})}{\|(s_x^{*'}, s_y^{*'}, s_z^{*'})\|} \tag{13}$$

Computation of the approach Vector $a(k)$: Practical seams curve have slowly-varying slopes. Since the sample points are assumed to lie close to each other. The curve between two sample points can be approximated by a straight line. This approximation leads to a plane which passes through at least three of the four sample points. The direction cosines of the plane are also the direction cosines of a vectors of normal to the plane. Since the weld torch is required to perpendicular to the local seam plane, the direction cosines of the approach vector $a(k)$ are specified as the negative of the direction cosines of the normal to the plane. the approach vector can be given by Equations (14)-(15)

$$v_1(k) = \frac{w_0(k+1) - w_0(k)}{\|w_0(k+1) - w_0(k)\|}$$
$$v_2(k) = \frac{w_4(k+1) - w_0(k)}{\|w_4(k+1) - w_0(k)\|} \tag{14}$$

The vector $a(k)$ is given by

$$a(k) = \frac{v_1(k) \times v_2(k)}{\|v_1(k) \times v_2(k)\|} \tag{15}$$

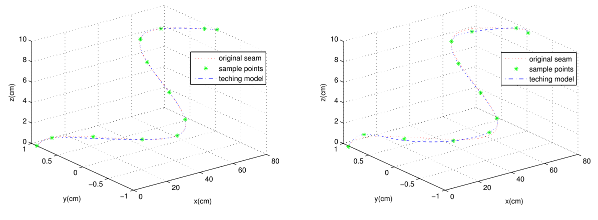
Computation of the normal Vector $n(k)$ The unit vector $n(k)$ is given by the cross-product

$$n(k) = a(k) \times o(k) \tag{16}$$

to form a right-handed coordinate system.

At this stage the orientation model of the 3D welding curved seam has been already obtained by using the equations(13),(15) and (16). Using the orientation model and the position model in the previous section, the position and orientation of the torch can be controlled and the tracking of 3D welding curved seam can be implemented. Since the Seam coordinate frame $[C(k)]$ is a discrete model, interpolation of the frame is required so as to obtain some frame that is not in the discrete model sets, which help to enhance the stability of the system.

In this section, a position model and an orientation model about V-type seam are set up. The position and orientation model of other kinds of welding seam such as butt weld, lap weld and fillet weld, are established by using similar method.



(a) no noise (b) include noise

Fig. 3. Self-teaching seam model

4. SIMULATION RESULTS

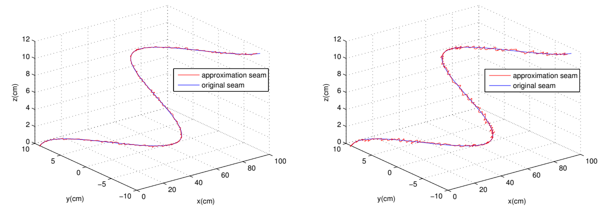
In this section, simulation about V-type seam model is considered. Firstly, the simulation of the self-teaching model is given. Then the performances of two position seam model are evaluated. Suppose that the coordinates of 3D curved seam suffer from the uniformly distributed noises or normally distributed noises with the maximum and minimum values of the noises being within the plus and minus 2% of the measurement range. The self-teaching model can be obtained by using the cubic spline interpolation method. The position model is computed by using parameter cubic spline least square fitting. The orientation model is obtained according to the position model and other edges characteristic points of the seam.

4.1 The simulation of self-teaching seam model

After the coordinates of the seam is obtained by using the visual system, the coordinates of the seam should be transformed into a number of control points, then cubic spline self-teaching model is obtained by using these control points. The self-teaching model can be used to design the macro motion control algorithm. Moreover, the self-teaching model help to gain the whole information of the seam so as to harmonize the macro motion and micro motion of the weld robot.

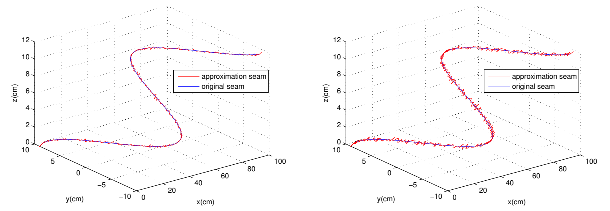
When the seam coordinates are free of noise, Fig.3(a) is obtained. In Fig.3(a), the red dot line represents original seam free of noise. The sign '*' stands for coarsely teach points. The green dash-dot line represents the cubic B-spline curve that is obtained by using the sample points. When the seam coordinates suffer from noise, Fig.3(b) is obtained. In Fig.3(b), the red dot line represents seam with noises and the sign '*' demonstrates coarsely sample points. The green dash-dot line represent cubic B-spline curve that is obtained by using the sample points with noises.

The self-teaching model is obtained by using these sample points with noises. Self-teaching has some advantages as follows. Firstly, the sample points are quietly few and this advantage helps to reduce the time of teaching and the effect of noises. Secondly, the model can predict the shape and curvature changes of the seam, which helps welding system to recognize seam environment and thus has strengthen the intelligence of the system. Thirdly, the model is beneficial to a better control of the position and



(a) normally distributed noise (b) uniformly distributed noise

Fig. 4. Polynomial position model under noises



(a) normally distributed noise (b) uniformly distributed noise

Fig. 5. Spline position model under noises

orientation of the torch. Although the self-teaching model have some advantages, the seam model has a big errors in some places as is shown in Fig.3(b). As such, it is necessary to set up a real-time seam model so as to reduces errors.

4.2 The simulation of the seam position model

In this section, the performances of different seam model methods are compared. Moreover, the effects of different noises to the model are also evaluated. For these purposes, uniformly distributed noises and normally distributed noises are considered mainly. Fig.4 shows the simulation results of the seam position model when the least square polynomial method is applied, where the seam position model under uniformly distributed noises is given in Fig.4(a) and the seam position model under normally distributed noises is shown in Fig.4(b). Fig.5 displays the simulation results of the seam position model when the least square cubic parameter B-spline method is applied, where the seam position model under uniformly distributed noises is given in Fig.5(a) and the seam position model under normally distributed noises is shown in Fig.5(b), respectively. Due to the existence of the different type of noises, it can be clearly seen that there is a different model errors in figures 4-5. From these figures it can be concluded that best position model has be obtained when these coordinates are subjected to the normally distributed noises and when the least square cubic parameter B-spline method are applied.

4.3 The simulation of the seam orientation model

The orientation model of the 3D welding curved seam can be obtained by seam position model and some other characteristic points of the seam. The orientation vector, the approach vector, the normal vector of the orientation model are given by equation (13), equation (15) and equation (16), respectively.

5. CONCLUSIONS

In this paper a novel modeling method for 3D curve welding seam is developed for a welding robot for large workpiece. Both a self-teaching seam model and a real-time seam model are established so as to accurately control position and orientation of torch, where the self-teaching model is established using a cubic B-spline interpolation function. This is followed by the establishment of a continuous position model for a V-type seam using a cubic parameter B-spline least square method. The orientation model of the seam is also obtained by using the position model and coordinates of seam characteristic points. It has been shown that the three models are the bases of macro and micro translational motion control and real-time tracking control. A comprehensive simulation has been carried out to justify the proposed modeling method. In order to compare the performances of the different position modeling method, further simulations have also been carried out to produce the modeling results of cubic parameter B-spline least square method and polynomial least square method.

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