A New Algorithm of Weaving Motion Using Bezier Spline

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Abstract: In this paper, we propose a new weaving trajectory algorithm for the arc welding of a articulated manipulator. The algorithm uses the theory of Bezier spline. We make a comparison between the conventional algorithms using Catmull-Rom curve and the new algorithms using Bezier spline. The proposed algorithm has been evaluated based on the MATLAB environment in order to illustrate its good performance. The algorithm has been implemented on to the industrial manipulator of DR6 so as to show its real possibility. Through simulations and real implementations, the proposed algorithm can result in high-speed and flexible weaving trajectory planning and can reduce the processing time because it needs one-half calculation compared to the conventional algorithm using Catmull-Rom curve.

Keywords: Planning Algorithm, Weaving Trajectory Control, Bezier Spline, Catmull-Rom Curve, Simple Weaving, Triangular Weaving

1. INTRODUCTION

When a robot performs arc welding, a welding torch must be woven along welding lines. Weaving motion is periodic on a high frequency and is perpendicular to a welding line. [1] The weaving motion is a typical example of flexible motion for a robot because the welding task of a robot should be performed in a similar manner as an experienced welding worker does. It is desirable that several tasks of welding should be feasible by developing new flexible and efficient algorithms of weaving motion to improve welding quality and productivity. Some control methods can improve weaving trajectories. One is accelerometer feedback, which has been investigated in the field of vibration control. [2]~[3] However, reliability is spoiled, which is one of the most important properties of industrial robots, because accelerometers must always be attached on arms when they do welding.

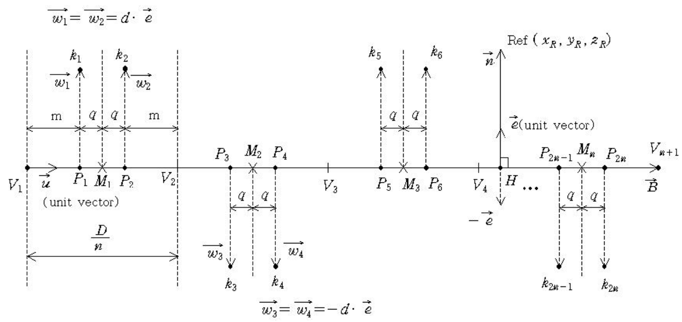
In this paper, weaving trajectories are improved for the arc welding of a 6 degrees of freedom (DOF) articulated robot manipulator such as DR6 robot (Doosan Mecatec Co., Ltd., Korea). For the case of DR6, only Catmull-Rom curve strategy has been used for weaving motion. This strategy has resulted in erroneous motion in the vicinity of starting and ending points. On this problem, Bezier spline algorithm has been incorporated in the proposed algorithm.

2. NEW WEAVING ALGORITHMS

The proposed algorithm is composed of simple weaving and triangular weaving motion.

2.1 Simple weaving motion algorithm

In the simple weaving motion, the starting point (V_1), the ending point (V_{n+1}), the reference point (Ref), the amplitude d, the smooth constant q and the number of weaving n are given. As shown in Fig. 1, first of all, we can find the unit vector **u** by the vector **B** connecting the starting point and the ending point. Second, we divide the starting point and ending point equally by n (the number of weaving sections) using the unit vector **u**. Third, the middle points M_i can find using V_i and V_{i+1}. And also, the point P_i (i=1,2,3, $\cdots$, 2n) can find using M_i and $\pm$q. Fourth, the vector **e** which is perpendicular to the vector **u** (the unit vector in the direction of connecting the starting and ending points) can be found while passing through the reference point as well. Fifth, the points k_i (i=1,2,3, $\cdots$,2n) can find using the point P_i , the amplitude d and the vector **e.**



d : weaving amplitude , q : smoothness constant
Fig. 1 Simple weaving motion

Consequently, the control points of Bezier spline in the first section, which are divided equally, become (V_1, k_1, k_2, V_2). That is, V_1 is the starting point. Two points k_1 and k_2 are in the direction of the vector **e**, which are decided by both the smoothness constant q and the weaving amplitude d as shown in Fig.1. The second point V_2 is one of the points, which are divided equally by n. The weaving direction in the first section is identical to the direction of vector **e**. The control points of Bezier spline are composed of (V_2, k_3, k_4, V_3), and the weaving direction is opposite to that of the previous section. In this way, the weaving movement using Bezier spline is repeated n times.

2.2 Triangular weaving motion algorithm

In the triangular weaving, a_1, b_1, c_1, d, step, and c (smoothness constant) are given. As shown in Fig. 2, first, ($a_1, a_2, \cdots, a_n$), ($b_1, b_2, \cdots, b_n$), ($c_1, c_2, \cdots, c_n$) should be calculated by Eq.(2), Eq.(3), Eq.(4). Second, we can be found ($k_{11}, k_{12}, \cdots, k_{1n}$), ($k_{21}, k_{22}, \cdots, k_{2n}$) by Eq.(6), Eq.(8). The calculated points become the control points of Bezier spline.

$$\vec{u} = \left(\frac{x_d - x_{c_1}}{D}, \frac{y_d - y_{c_1}}{D}, \frac{z_d - z_{c_1}}{D}\right) \quad (1)$$

where, $D = \sqrt{(x_d - x_{c_1})^2 + (y_d - y_{c_1})^2 + (z_d - z_{c_1})^2}$

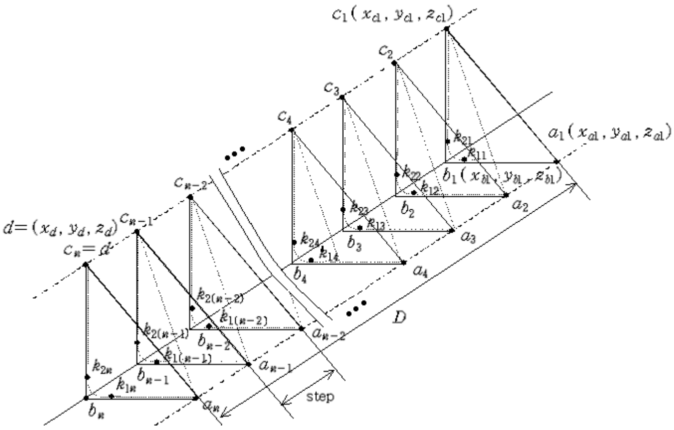


Fig. 2 Triangular weaving motion

$$a_i = a_1 + \vec{u} \times step \times (i-1) \quad (i = 1,2,3,\cdots,n) \quad (2)$$

$$b_i = b_1 + \vec{u} \times step \times (i-1) \quad (i = 1,2,3,\cdots,n) \quad (3)$$

$$c_i = c_1 + \vec{u} \times step \times (i-1) \quad (i = 1,2,3,\cdots,n) \quad (4)$$

$$\overrightarrow{u_{k1}} = \left(\frac{x_{a_1} - x_{b_1}}{D_1}, \frac{y_{a_1} - y_{b_1}}{D_1}, \frac{z_{a_1} - z_{b_1}}{D_1}\right) \quad (5)$$

where, $D_1 = \sqrt{(x_{a_1} - x_{b_1})^2 + (y_{a_1} - y_{b_1})^2 + (z_{a_1} - z_{b_1})^2}$

$$k_{1i} = b_i + \overrightarrow{u_{k1}} \times c \quad (i = 1,2,3,\cdots,n) \quad (6)$$

$$\overrightarrow{u_{k2}} = \left(\frac{x_{c_1} - x_{b_1}}{D_2}, \frac{y_{c_1} - y_{b_1}}{D_2}, \frac{z_{c_1} - z_{b_1}}{D_2}\right) \quad (7)$$

where, $D_2 = \sqrt{(x_{c_1} - x_{b_1})^2 + (y_{c_1} - y_{b_1})^2 + (z_{c_1} - z_{b_1})^2}$

$$k_{2i} = b_i + \overrightarrow{u_{k2}} \times c \quad (i = 1,2,3,\cdots,n) \quad (8)$$

The control points of Bezier spline in the first section become (a_1, k_{11}, k_{21}, c_1). Those of the second section become (a_2, k_{12}, k_{22}, c_2). The first Bezier spline and the second one are connected by straight line using point c_1 and point a_2. In this way, triangular weaving is completed until it comes to the n-th section .

3. COMPARISON

We make a comparison between the conventional algorithms using Catmull-Rom curve[4]~[5] and the new algorithms using Bezier spline.

3.1 Simple weaving motion

For simple weaving trajectories, as shown in Fig. 3, the conventional algorithm using Catmull-Rom curve, even though it can control the smoothness of a curve by using a constant c ($0 \le c \le 1$), needs two times calculation for obtaining a third-order curve from 4 via points, compared to the proposed algorithm. On the other hand, as shown in Fig. 4, the proposed algorithm using Bezier spline needs just one-half calculation from 4 control points as well as controlling the smoothness of a curve through control points. It means that the proposed algorithm can make its realization on industrial robots easier than the conventional algorithm in the sense of computational load.

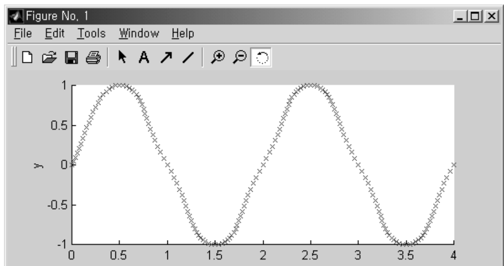


Fig. 3 Simple weaving motion using catmull-rom curve

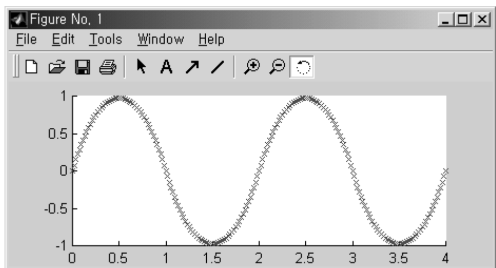


Fig. 4 Simple weaving motion using bezier spline

3.2 Triangular weaving motion

For triangular weaving trajectories, as shown in Fig. 5 and Fig. 6, the conventional algorithm using Catmull-Rom curve can make weaving trajectories [except complete triangular weaving, i.e., c=0] escape from normal welding paths so that a welding torch can penetrate into the material to be welded.

On the other hand, as shown in Fig. 7, the proposed algorithm using Bezier spline does not penetrate into the material to be welded while controlling the smoothness of a weaving trajectory passing through the vertex of a triangle. In addition, for the remaining part of a weaving using catmull-rom curve trajectory except the vertex of a triangle, the proposed algorithm can generate weaving trajectories with keeping constant space between the material to be welded and a welding torch.

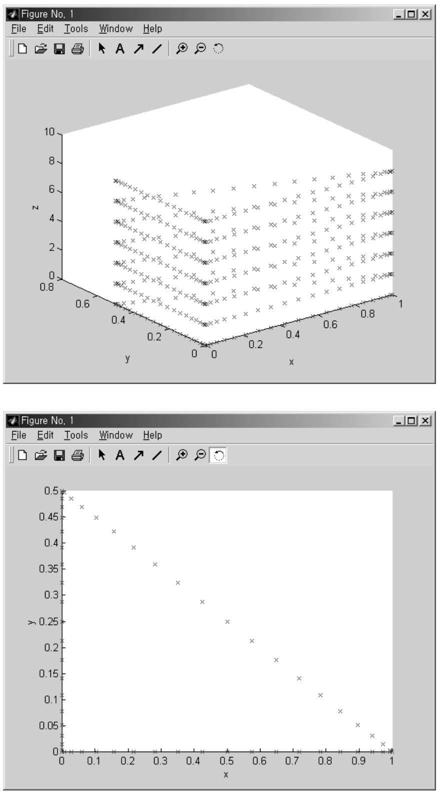
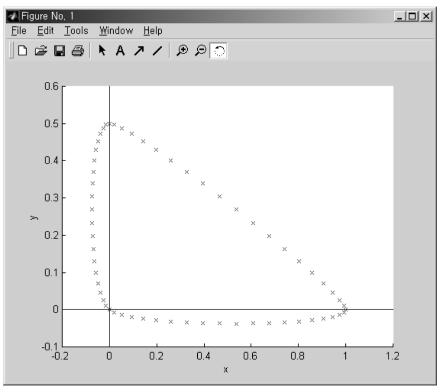
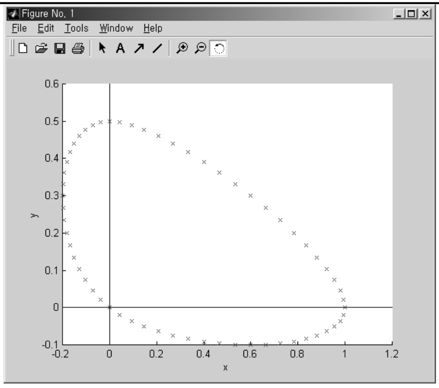


Fig. 5 Triangular weaving motion using catmull-rom curve at c=0



(a) c=0.3



(b) c=0.8

Fig. 6 Triangular weaving motion

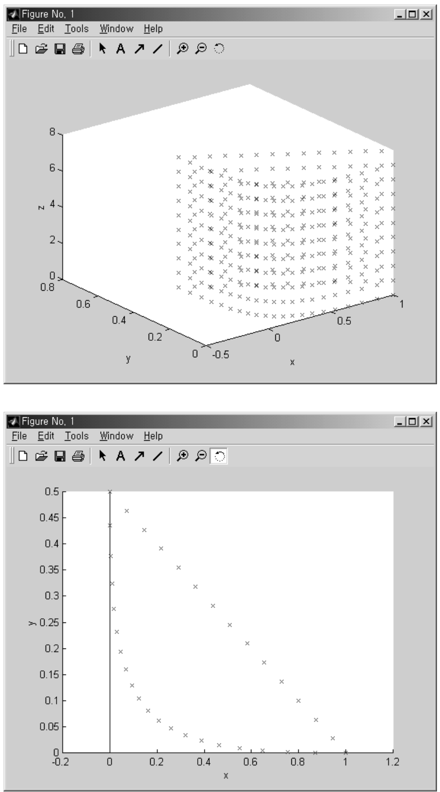


Fig. 7 Triangular weaving motion using bezier spline at c=0.1

4. SIMULATION

The proposed algorithm using bezier spline has been evaluated based on the MATLAB[6] environment in order to illustrate its good performance.

4.1 Simple weaving result of simulation

Figure 8 shows the simulation result for simple weaving motion based on the MATLAB environment. In this figure, the starting point, the ending point and the reference point are (5, 8, 0), (54, 37, 0), and (45, 23, 0), respectively, while the weaving amplitude d and the smoothness constant q are given by 2 and 0.4, respectively.

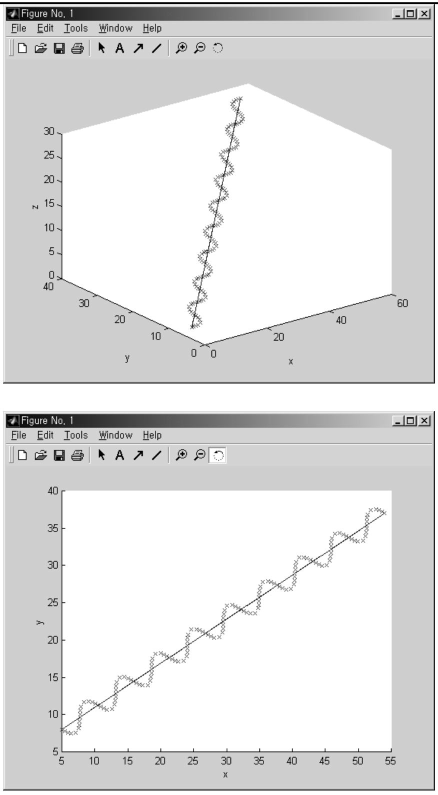


Fig. 8 Simple weaving motion result based on MATLAB

4.2 Triangular weaving result of simulation

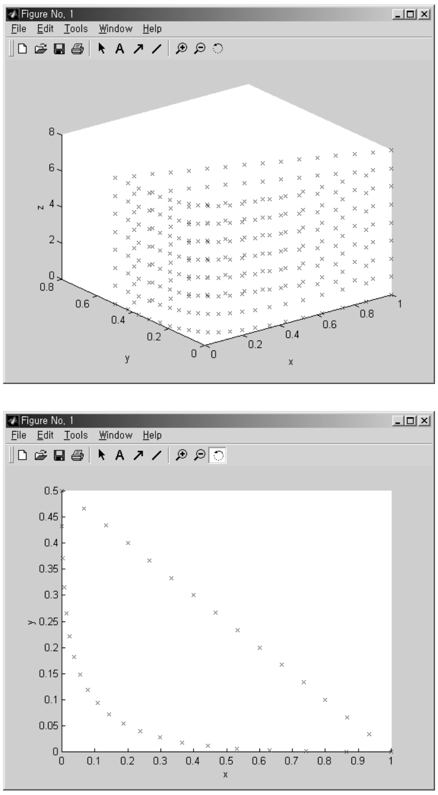


Fig. 9 Triangular weaving motion result based on MATLAB

Figure 9 shows the simulation result for triangular weaving motion based on the MATLAB environment. Referring to Fig. 2, a_1, b_1, c_1, and d are given by (1, 0, 0), (0, 0, 0), (0, 0.5, 0), and (0, 0.5, 8), respectively, while step=0.8 and the smoothness constant c=0.1.

5. CONCLUSION

In this paper, we have proposed a new weaving trajectory algorithm for the arc welding of an articulated manipulator. The algorithm uses the theory of Bezier spline. We make a comparison between the conventional algorithms using Catmull-Rom curve and the new algorithms using Bezier spline. The algorithm has been implemented on to the industrial manipulator of DR6 so as to show its real possibility. Through simulations and real implementations, the proposed algorithm can result in high-speed and flexible weaving trajectory planning and can reduce the processing time because it needs one-half calculation compared to the conventional algorithm using Catmull-Rom curve.

6. ACKNOWLEDGEMENT

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