A Bézier Curve-Based Approach for Path Planning in Robot Soccer

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Abstract. This paper presents an efficient, Bézier curve-based path planning approach for robot soccer, which combines the function of path planning, obstacle avoidance, path smoothing and posture adjustment together. The locations of obstacles are considered as control points of Bézier curve, then according to the velocity and orientation of end points, a smooth curvilinear path can be planned in real time. For the sake of rapid reaching, it is necessary to decrease the turning radius. Therefore a new construction of curve is proposed to optimize the shape of Bézier path.

Keywords: Bézier curve, path planning, robot soccer.

1 Introduction

Robot soccer is a classic integration of robotics and artificial intelligence (AI). It almost covers the vast majority of important issues in these two fields. Robot soccer studies how mobile robots can be built and trained to play the game of soccer [9]. In the robot soccer game, robots stay in a dynamic environment all the time. Ball and two sides of robots move continually, which changes the situation of the game, while the teammate robots need to make decisions and take actions according to the changing situation, to gain ascendency and win the game by means of teamwork. In order to implement the team strategies, the robots need to plan a collision-free and time optimal path in real time. Therefore, path planning is the basis of robot movement, which is a kind of planning control in an unknown and dynamic environment. At present, there are two most important international competitions in the field of robot soccer, that is FIRA and RoboCup. In this paper, a Bézier curve-based method of path planning is presented for robot soccer game.

The paper is organized as follows. The path planning problem of robot soccer is discussed in Section 2. Section 3 presents a novel Bézier curve-based path

A. Abraham et al. (eds.), *Innovations in Bio-inspired Computing and Applications*,
Advances in Intelligent Systems and Computing 237,
DOI: 10.1007/978-3-319-01781-5_10,

planning approach for robot soccer. Section 4 describes the proposed path planning optimization techniques. Finally, Section 5 draws the conclusions of this work.

2 Path Planning in Robot Soccer

On the issue of path planning, a lot of approaches were presented, such as artificial potential field (APF) [2, 7, 10, 16], genetic algorithm (GA), fuzzy, artificial neural network (ANN), rapidly-exploring random tree (RRT) [1, 8, 15], and so on. All the approaches could be classified as AI methods [16,19] except APF and RRT. The AI methods are associated with optimization algorithms, resulting in optimal global path planning. However, optimization algorithms are relatively complex, time-consuming, and are not very useful for real-time applications. RRT is a universal algorithm, it can deal with all types of obstacles. However, it can not produce a smooth path.

APF [7,12,13,17] is a virtual force method, which has been studied extensively for autonomous mobile robot path planning [5]. There are many advantages of this method. However, there exist two problems that are inherent to the artificial potential field [11,14,20]. First, the robot is likely to be in a trap of local minima. The velocity and direction of the robot in the field depend on the magnitude and direction of the vector force, it means the robot can not move if the resultant force is zero, and that is why the robot could run into the trap of local minima. Secondly, in the area where obstacles are gathering, the planned path by APF presents a problem of oscillation. In this situation, although the robot can avoid obstacles and reach its destination point, the robot among the obstacles varies direction again and again, which may interfere with the movement fluency of the robot. Unless the robot moves slowly, the path does not meet the motion performance of robot nor the tactic of soccer game. If the robot move along the oscillating path, it will absolutely be under the heavy siege by opponents.

Jolly *et al.* [6] proposed a Bézier curve-based approach of path planning for a mobile robot in a multi-agent robot soccer system. Their work is applied to the MiroSot small league. The approach only considers a third degree Bézier curve, where the lengths of the polygon sides d_1 and d_2 are the key parameters, and therefore, no more complex situation can be considered. They proposed an iterative algorithm to determine d_1 and d_2, then a path can be planned by the lengths of d_1 and d_2. If the robot will intersect with an obstacle, the path is re-planned by changing parameters d_1 and d_2. The accuracy of the Bézier path depends on the accuracy of the pose estimation algorithm, and the optimization of the planned path is subjected to the parameters d_1 and d_2.

In robot soccer, path planning has two important functions, that is, obstacle avoidance and path smoothing. If there is no obstacle avoidance mechanism, collision will happen frequently in the game, which is going to stop the flow of the soccer game and damage the robot hardware. Furthermore, path planning must take into account the state of the initial and destination points, including the location and orientation, so that the robot can play the ball directly without posture adjustment when arriving the destination point. This requires the system to plan a smooth path, then the robot can adjust its posture through a smooth curvilinear movement in the process of moving to destination point. The presented approach in this paper combines path planning, obstacle avoidance, path smoothing and posture adjustment together.

3 Bézier Path Planning

Bézier Curves [3,4] were invented in 1962 by the French engineer Pierre Bézier for designing automobile bodies. Today Bézier Curves are widely used in computer graphics, computer aided geometric design and other related fields.

A Bézier curve is defined by a set of control points P_0 through P_n, where n is called its order ($n = 1$ for linear, 2 for quadratic, etc.). The first and last control point are always the end points of the curve; however, the intermediate control points (if any) generally do not lie on the curve.

Generally, we can define the Bézier curve as

$$P(t) = \sum_{i=0}^{n} b_{i,n}(t)\, P_i \,,\; t \in [0,1] \,, \tag{1}$$

where t is a normalized time variable, the points P_i are called *control points* for the Bézier curve, the polynomials

$$b_{i,n}(t) = C_n^i\, t^i (1 - t)^{n-i} \,,\; i = 0, 1, \cdots, n \,, \tag{2}$$

are known as *Bernstein basis functions* of degree n, and the binomial coefficient

$$C_n^i = \frac{n!}{i!(n - i)!} \,. \tag{3}$$

The soccer robot in MiroSot moves on two parallel wheels, with the centers of these wheels aligned, resulting in a common surface normal. For this wheel assembly, the robot turning is induced by the difference in the velocities of the two wheels. In other words, we control the robot through controlling the rotational speed of two independent wheels.

Let $P(t)$ be the location of robot. The generalized coordinates are defined in Fig. 1. Then we have

$$P(t) = [x \;\; y \;\; \theta]^T \,. \tag{4}$$

If the rotational speed of the left and the right wheels are ω_L and ω_R respectively, then assuming no slipping of the wheels, the wheel velocities at the contact point are respectively

$$V_L = r\,\omega_L \,, \tag{5}$$

$$V_R = r\,\omega_R \,, \tag{6}$$

where r is the radius of the wheel.

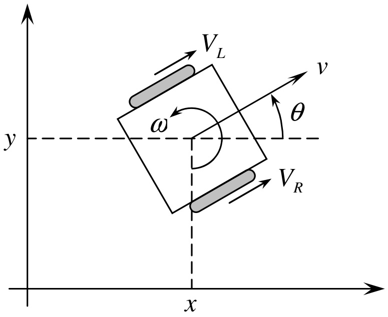

Fig. 1. Generalized Coordinates of MiroSot Robot

Let υ be the tangential velocity of the robot at its center and ω the angular velocity of the robot. Then we have

$$\upsilon = \frac{V_R + V_L}{2} = r \cdot \frac{\omega_R + \omega_L}{2}, \tag{7}$$

$$\omega = \frac{V_R - V_L}{L} = r \cdot \frac{\omega_R - \omega_L}{L}, \tag{8}$$

that is

$$\begin{bmatrix} \upsilon \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ \frac{r}{L} & -\frac{r}{L} \end{bmatrix} \begin{bmatrix} \omega_R \\ \omega_L \end{bmatrix}, \tag{9}$$

where L is the distance between the two wheels. Then we can solve the rotational speed of the wheels by

$$\begin{bmatrix} \omega_R \\ \omega_L \end{bmatrix} = -\frac{L}{r^2} \begin{bmatrix} -\frac{r}{L} & -\frac{r}{2} \\ -\frac{r}{L} & \frac{r}{2} \end{bmatrix} \begin{bmatrix} \upsilon \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{1}{r}\upsilon + \frac{L}{2r}\omega \\ \frac{1}{r}\upsilon - \frac{L}{2r}\omega \end{bmatrix}. \tag{10}$$

The kinematics model of the robot is

$$\dot{P}(t) = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \upsilon \\ \omega \end{bmatrix}. \tag{11}$$

Suppose that the robot can not slip in a lateral direction, hence

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0. \tag{12}$$

Eq. (12) is called the nonholonomic constraint of the robot.

In the following discussion, we would illustrate a fourth-order Bézier path of MiroSot robot (Fig. 2). For the sake of concision, we will omit the independent

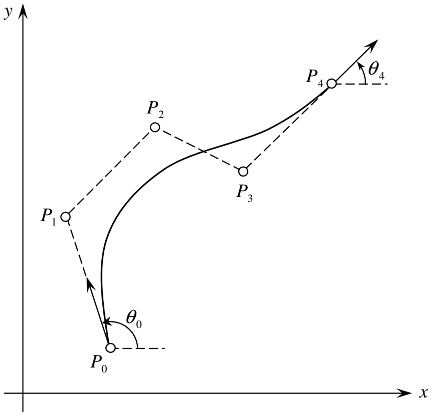

Fig. 2. Fourth-order Bézier Path of MiroSot Robot

variable and abbreviate $b_{i,n}(t)$ to $b_{i,n}$. Furthermore, we would use the notation b_{in} for $b_{i,n}$ whenever there is no confusion.

Suppose there are five control points, P_0, P_1, P_2, P_3 and P_4, which uniformly define the fourth-order Bézier curve (Fig. 2). The control points P_1 and P_3 are defined to fulfill the velocity and orientation requirements in the path. According to Eq. (1), the planned Bézier path vector could be expressed as

$$\begin{aligned} P(t) &= b_{04} P_0 + b_{14} P_1 + b_{24} P_2 + b_{34} P_3 + b_{44} P_4 \\ &= (1-t)^4 P_0 + 4t(1-t)^3 P_1 + 6t^2(1-t)^2 P_2 \\ &\quad + 4t^3(1-t) P_3 + t^4 P_4 . \end{aligned} \tag{13}$$

The tangential velocity of x-component and y-component, and angular velocity are defined as the derivative of the path vector,

$$\begin{aligned} [\, v_x(t) \quad v_y(t) \quad \omega \,]^T &= \frac{dP(t)}{dt} \\ &= 4 b_{03} (P_1 - P_0) + 4 b_{13} (P_2 - P_1) \\ &\quad + 4 b_{23} (P_3 - P_2) + 4 b_{33} (P_4 - P_3) . \end{aligned} \tag{14}$$

Generally, the velocity state of a n-order Bézier path is

$$[\, v_x(t) \quad v_y(t) \quad \omega \,]^T = \frac{dP(t)}{dt} = \sum_{i=0}^{n-1} n \,(P_{i+1} - P_i)\, b_{i,n-1} . \tag{15}$$

Additionally, the tangential velocity of the robot can be written as

$$v(t) = \sqrt{v_x^2(t) + v_y^2(t)} . \tag{16}$$

The v and ω can be obtained from joint solution of Eq. (15) and Eq. (16). Substituting v and ω in Eq. (10) gives the rotational speed of the wheels ω_R

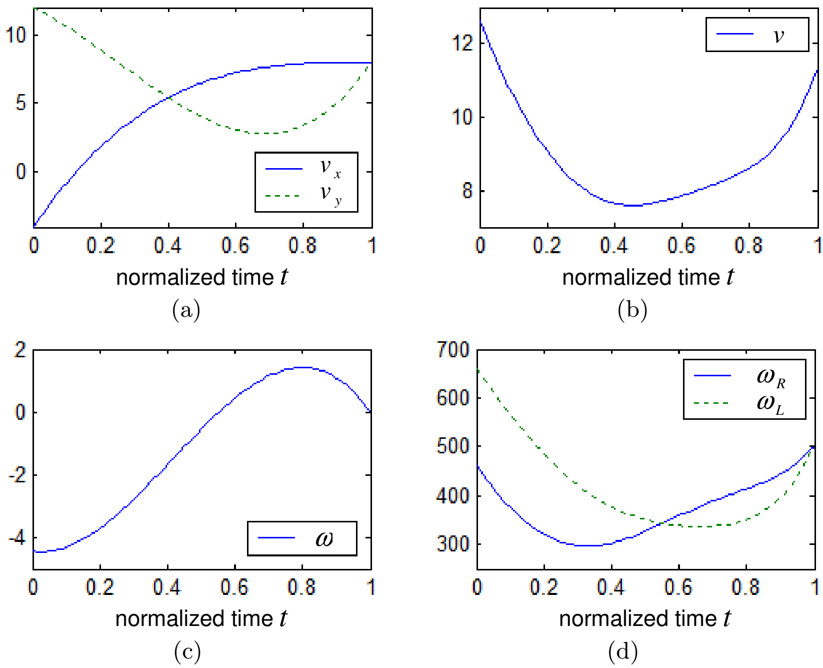

Fig. 3. Motion Control of MiroSot Robot (a) velocity of x-component and y-component; (b) tangential velocity of robot; (c) angular velocity of robot; (d) rotational speed of the robot wheels

and ω_L which are the final control variables of the motor in the MiroSot soccer robot. Then the robot can move along the planned Bézier path to its destination point.

Fig. 3 displays the waveforms of some control variables for the MiroSot robot on the fourth-order classical Bézier path shown in Fig. 2. Additionally, Fig. 3(d) shows the rotational speed of left and right robot wheel. We have known that the robot turning is induced by the difference in the velocities of the two wheels. Consequently, if we control the rotational speed of robot wheels in accordance with the calculated values in Fig. 3(d), the robot will move along the planned classical Bézier path as shown in Fig. 2.

4 Optimized Bézier Path Planning

Fig. 2 shows the planned Bézier path for the robot. In the domain, the robot current position is (300, 100), two obstacles stand at (400, 600) and (600, 500), the ball lies at (800, 700). There is a virtual control point at (200, 400). The robot is not able to turn sharply, then we set a virtual control point ahead of the direction of robot current velocity so that the robot can turn to its destination point smoothly. And we can as well set another virtual control point to control

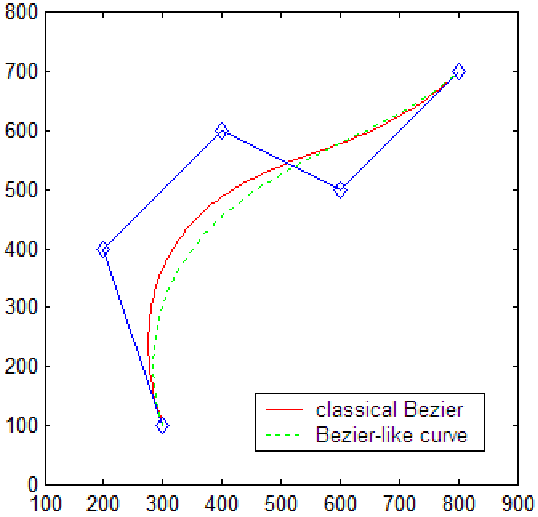

Fig. 4. Application of Bézier Curve in Path Planning

the robot hitting angle at the destination point if necessary. For the sake of rapid reaching, it is necessary to decrease the turning radius. Therefore we construct a new curve, which is on the basis of classical Bézier curve, to adjust the shape of Bézier path.

We have known that the Bézier curve is defined on the Bernstein basis functions, so we can adjust the shape of curve through introducing parameters into basis functions [18].

The *Bernstein-like basis functions* can be expressed explicitly as

$$b_{i,n}^{*}(t) = \left(1 + \frac{3C_{n-2}^{i-1} + C_{n-1}^{i} - C_{n}^{i}}{C_{n}^{i}}\lambda - \frac{2C_{n-1}^{i}}{C_{n}^{i}}\lambda t + \lambda t^{2}\right) C_{n}^{i} t^{i} (1-t)^{n-i}, \tag{17}$$

where $\lambda \in [-1, 1]$, $t \in [0, 1]$, $i = 0, 1, \cdots, n$ and $n \geq 2$, we set $C_q^p = 0$ in case of $p = -1$ or $p > q$. Then the Bézier-like path can be constructed by

$$P^{*}(t) = \sum_{i=0}^{n} b_{i,n}^{*}(t) P_i . \tag{18}$$

According to Eq. (17) and Eq. (18), we can reconstruct the Bézier path. The green dotted line in Fig. 4 displays a planned Bézier-like path in the case of $\lambda = -0.8$, its turning radius is smaller that that of classical Bézier path obviously. Consequently, the robot can reach its destination point more rapidly. In practice, the effect is more remarkable in the case of fewer obstacles. In Fig. 5, the green dashed Bézier-like path has much smaller turning radius than red solid classical Bézier path does.

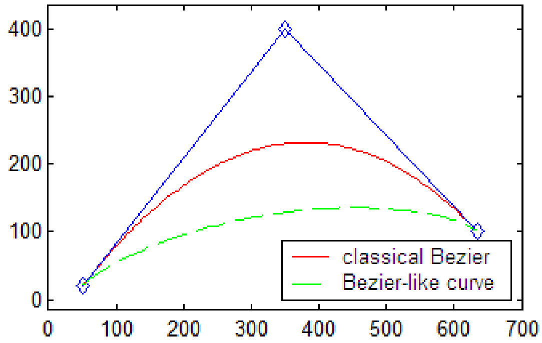

Fig. 5. Bézier-like Curve in Path Planning

5 Conclusion

An efficient and effective approach of path planning for soccer robots has been presented in this paper. In this approach, the current location of robot could be one of the curve's end points, another end point depends on the role of the robot. If a robot is assigned to be a striker, then the position of the ball is another end point of the planned path for the striker. All the robots are treated as obstacles. The end points and obstacle points are control points, by which a Bézier curve can be planned. In order to reduce the turning radius, a new construction of curve is proposed to optimize the shape of Bézier path. Because of the characteristic of Bézier curve, the planned path can avoid obstacles automatically. Furthermore, this approach combines the function of path smoothing and posture adjustment together.

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