ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

Research on the motion state of bench dragon based on mechanism modeling

Zhongwang Ma*, Chengjin Wu, Zhou Yao

College of Metrology Measurement and Instrument, China Jiliang University, Hangzhou, 310018, China
**Corresponding author: 15824466693@163.com*

Abstract: *"Bench Dragon", also known as "Coiled Dragon", is a traditional local folk cultural activity in the regions of Zhejiang and Fujian. People link tens or even hundreds of benches end to end to form a sinuous bench dragon. Generally speaking, on the premise that the dragon dance team can freely coil in and out, the smaller the area required for the coiled dragon and the faster the moving speed, the better the appreciation effect. Therefore, this paper proposes a mechanism model for the movement state of the bench dragon based on the variable step-size search algorithm. Firstly, a plane rectangular coordinate system is established, and the equal relationship is established by using the curve integral and the path calculation formula to obtain the recurrence relationship of the positions between the bench handles. The derivative of the position equation is taken to obtain the recurrence relationship of the speeds between the handles. Secondly, the termination situation of the coiling-in of the dragon dance team is analyzed, the minimum coiling pitch under the condition of no collision is studied, and the variable step-size search algorithm is applied for the solution, and the bisection method is combined to improve the calculation efficiency. Finally, the turning curve model is established and the length of the turning curve is analyzed. The experimental results show that the variable step-size search algorithm proposed in this paper has a good effect and provides an accurate reference strategy for the dragon dance team to determine the positions and speeds for coiling in and out.*

Keywords: *Connector motion state, mechanism model, variable step search*

1. Introduction

Originating in China, the dragon dance is a unique art form with a deep traditional Chinese culture [1] . It replaces the traditional dragon body with a bench, which has a unique symbolic meaning and high ornamental value. In Panlong performances, spatial layout and speed control are crucial to the visual experience of the audience. The smaller space optimization and faster travel speed make the dragon dance compact and orderly, creating a strong sense of visual concentration and artistic atmosphere. Therefore, it is of great practical significance to study the spatial and velocity layout of the "bench dragon" to improve the viewing effect of the performance.

At present, domestic and foreign scholars have conducted research on the construction of path planning models and verified the feasibility of various models. Wang et al. [2] combined an improved Dijkstra algorithm based on priority queues with three different approaches. In order to solve the problem of unreasonable scheduling of the same type of agricultural machinery, an improved working path method was proposed to minimize the path cost. Carmine Maria Pappalardo et al. [3] constructed a multi-body model of mechanical system based on recursive Lagrangian method and proposed a method to solve the dynamics and control problems of multi-body mechanical system. Yao et al. [4] established a unified optimization model of multi-body system dynamics with multi-point contact and collision based on Gaussian minimum constraint principle for the discontinuous dynamics problem of multi-body system with multi-point contact and collision, and verified that Gaussian optimization method can effectively solve the dynamics model of multi-body system with unilateral and bilateral constraints. Belal A. Elsayed et al. [5] considered a snake-like robot with N links connected by N-1 joints. The spiral rolling gait equation and kinematics-based controller were used to realize the spiral motion of the snake-like robot and the effectiveness of the control strategy was verified through experiments. Li et al. [6] proposed a motion planning algorithm for multi-joint snake robot based on the improved serpentine curve equation, obtained the motion trajectory of the multi-joint snake robot, and analyzed the influence of different parameters on the forward speed of the robot. Guo et al. [7] designed an adaptive sliding mode control method for speed and position tracking control of high-speed trains based on the detailed model and the neural network minimum parameter learning algorithm, and rigorously proved the stability of the proposed control method. Guoshuang S et al. [8] gave a description method for the relationship between the absolute motion equation and the relative motion equation of a moving point in the compound motion of a point, and applied it to determine the relative motion trajectory when different moving points and moving systems are selected in a planar motion mechanism. GAO et al. [9] proposed a method for representing the velocity and acceleration of the involved point using an analytical method. Sanh D et al. [10] used the transfer matrix method to study the involved velocity problem of a planar mechanism.

Compared with the previous methods, this paper uses a recursive model based on the Archimedean spiral and avoids using analytical solutions to obtain accurate solutions. This is highly applicable to solving the spatial and speed layout problems of the "bench dragon" in this paper. The improved Dijkstra algorithm based on priority queue proposed by Wang et al. [2] is computationally complex. Due to the large number of benches in the "bench dragon", the optimization difficulty of this algorithm is further increased, and the solution efficiency is not high. Carmine Maria Pappalardo et al. [3] constructed a multi-body model of the mechanical system based on the recursive Lagrangian method. Due to the large number of benches, they solved each "dragon body" step by step until they solved the benches at the "dragon tail". Because numerical simulation is used, the error will gradually increase. Belal A. Elsayed et al. [5] constructed the motion state model of the snake-like robot by analyzing each section from the head to the tail of the snake . A large number of approximations were used in this process, which would cause error accumulation. In addition, the analysis based on multi-body dynamics in theoretical mechanics [8-10] requires more data such as the motion direction between each monomer that are not in this problem to solve, so it is not applicable.

Based on the analysis of the research results of scholars at home and abroad, this paper proposes a bench dragon motion state mechanism model based on a variable step-size search algorithm, and applies it to the path and speed layout of the dragon dance team's coiling in and out. On this basis, the kinematic model is experimentally simulated to verify the rationality of the model. The main contents of the full paper can be summarized as follows: First , the equation is established through curve integration to obtain the position and speed information of each handle of the dragon dance team, and the recursive relationship between the dragon head-dragon body and the dragon body-dragon body is established; then, the two termination situations of the dragon dance team's coiling were analyzed and the minimum coiling pitch under the condition of no collision was calculated; finally, the turning curve model is established and its length is solved.

2. Determination of the position and speed information of each handle of the dragon dance team

The dragon team enters clockwise along an isometric spiral with a pitch of 0.55. To get the velocity of the handle and the relationship between the coordinates and time, you first need to determine the expression of this equidistant spiral. First, the polar coordinate system is constructed, and in the polar coordinate system there are:

$$r = a + b\theta \tag{1}$$

Here a represents the initial radius of the spiral at $\theta = 0$ which is 8.8 and b represents the pitch of the spiral which is 0.55.

The speed of the faucet handle is constant, and the speed here is considered to be the speed along the spiral. Firstly, the relationship between the spiral arc length $L(\theta)$ and the polar angle θ is analyzed. Integrating L on $(0, \theta)$ yields:

$$L(\theta) = \int_0^{\theta} \sqrt{(a + b\theta')^2 + b^2} d\theta' = vt \tag{2}$$

Through equation (2), the functional relationship between θ and t can be obtained, i.e., $\theta(t)$, and then the relationship between arc length and time can be obtained. Then we can get the relationship between coordinates and time:

$$\begin{cases} x(t) = (a + b\theta(t))cos\theta(t) \\ y(t) = (a + b\theta(t))sin\theta(t) \end{cases} \tag{3}$$

Simultaneous equations (2) and (3) can be used to obtain the position information of the faucet at each time point. According to the derivative of equation (4), the functional relationship between velocity and the polar angle is established, and the velocity vector corresponding to the polar angle of the faucet

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

is obtained:

$$\begin{cases} v_x = (dx/d\theta)\cdot(d\theta/dt) \\ v_y = (dy/d\theta)\cdot(d\theta/dt) \end{cases} \Rightarrow \frac{v_x}{v_y} = \frac{dx}{d\theta}\Big/\frac{dy}{d\theta} \tag{4}$$

Let the coordinates of the ith front handle be $(x_i(t), y_i(t))$, there are 223 benches in total, and the 224th front handle represents the rear handle of the 223rd bench. The distance between the two holes of the ith bench is d_i, which is a fixed value. Thus there are:

$$\left(x_i(t) - x_{i+1}(t)\right)^2 + \left(y_i(t) - y_{i+1}(t)\right)^2 = d_i^2 \quad i = 1,2,\ldots,223 \tag{5}$$

Simultaneous (3) and (5) can obtain the position of each bench joint with respect to time. It is important to note that there are multiple solutions that satisfy the above equation, so the polar angles need to be limited, as in Eq. (6):

$$\overline{\theta_{i+1}(t)} = \max\{\theta_{i+1}(t) | \theta_{i+1}(t) < \theta_i(t)\} \quad i = 1,2,\ldots,223 \tag{6}$$

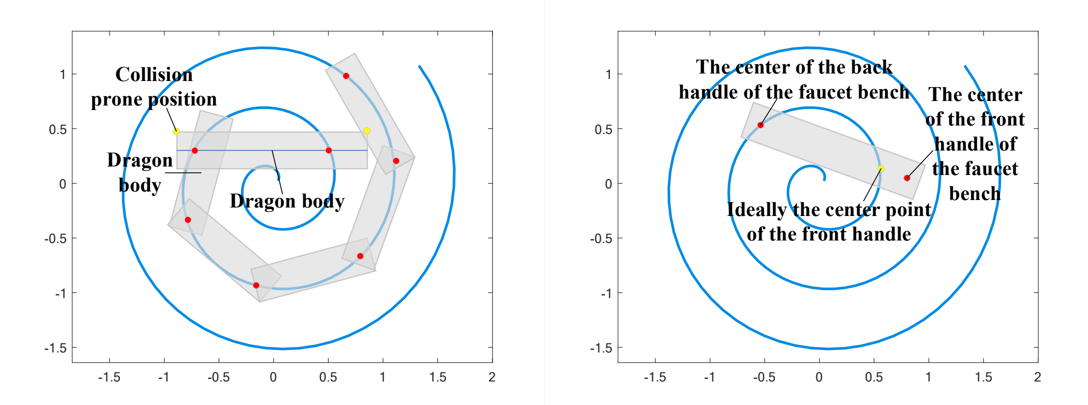
On the premise that the velocity vector of the previous point is known, the velocity vector of the current point is derived. Since the spacing between the front and rear handles of each bench is the same, it can be assumed that the components of the velocity of these two points on the line are the same, that is, the difference between the velocity vectors is perpendicular to the line. Let the velocity vector of the $i+1$ bench front handle be $\overrightarrow{v_{i+1,1}(t)} = (v_{i+1,1}^x(t),\ v_{i+1,1}^y(t))$, then we have:

$$\left(\overrightarrow{v_{i,1}(t)} - \overrightarrow{v_{i+1,1}(t)}\right)\cdot\left(x_i(t) - x_{i+1}(t), y_i(t) - y_{i+1}(t)\right) = 0 \quad i = 1,2,\ldots,223 \tag{7}$$

Simultaneous (4) and (7) can obtain the recursive velocity relation of the i+1st front handle with respect to the i-th front handle.

3. Minimum disc pitch without collision

3.1 Determination of termination



(a) A collision occurred *(b) Lack of space*

Figure 1 Two termination scenarios

(1) Because the faucet bench is connected to the first dragon bench by a handle, there is always an overlapping area between the benches, so overlapping adjacent benches does not count as a collision. As the dragon dance team continues to coil in, the dragon dance team will present a state as shown in Figure 1 (a): with the reduction of the spiral circle, the radius of the spiral gradually decreases, and the distance between the dragon head bench and the dragon body will continue to approach, because the dragon dance team coils clockwise along the helix, so the outer vertex of the dragon head bench will be the easy contact point with the dragon body bench, that is, the two points on the outside of the dragon head fall into one of the rectangles determined by the dragon body and are judged to collide.

First, push out the coordinates of the 4 boundary vertices of the bench through the coordinates of the front and rear handles. The rectangle is known to be w wide and l long. The two aperture centers are located on the centerline of the bench. The connecting vector at the center of the aperture of the two adjacent handles can be expressed as: $(x_{i+1} - x_i, y_{i+1} - y_i)$. Thus, a vector perpendicular to this line can be expressed as:

$$\vec{n} = (y_i - y_{i+1}, x_{i+1} - x_i) \tag{8}$$

After normalizing the vector obtained by Eq. (8) and multiplying it by half the width of the rectangle, it is:

$$\vec{u} = \vec{n}/\|\vec{n}\| \cdot 0.5w \tag{9}$$

Next, you can get the coordinates of the four vertices of the ith bench:

$$V_{1,2}^i = (x_i, y_i) \pm \vec{u} \qquad V_{3,4}^i = (x_{i+1}, y_{i+1}) \pm \vec{u} \quad i = 1,2,\dots,223 \tag{10}$$

Therefore, the collision between the dragon head and the dragon body can be recorded as:

$$V_j^i \in R_i \quad i = 1,2,\dots,223 \quad j = 1,2,3,4 \tag{11}$$

Among them, R_j represents the rectangular area of the j-th dragon bench.

The collision detection method is the vector cross product method, and the specific process is as follows:

For a point P outside an arbitrary rectangular region, firstly, the diagonal vector of the rectangular region determined by the bench is calculated, and the four vectors determined by the point P to be judged and each vertex of the rectangular region are calculated, and then the cross product is calculated with the obtained vectors, as shown in (12):

$$\begin{matrix} \textit{Diagonal vector of a rectangle} \\ \overrightarrow{V_1^i(t)V_3^i(t)} \quad \overrightarrow{V_2^i(t)V_4^i(t)} \\ \textit{Vectors determined by the vertices of the rectangle and P points} \\ \overrightarrow{P(t)V_1^i(t)} \quad \overrightarrow{P(t)V_2^i(t)} \quad \overrightarrow{P(t)V_3^i(t)} \quad \overrightarrow{P(t)V_4^i(t)} \end{matrix} \Rightarrow \begin{matrix} \overrightarrow{P(t)V_1^i(t)} \times \overrightarrow{V_1^i(t)V_3^i(t)} ① \\ \overrightarrow{P(t)V_2^i(t)} \times \overrightarrow{V_2^i(t)V_4^i(t)} ② \\ \overrightarrow{P(t)V_3^i(t)} \times \overrightarrow{V_1^i(t)V_3^i(t)} ③ \\ \overrightarrow{P(t)V_4^i(t)} \times \overrightarrow{V_2^i(t)V_4^i(t)} ④ \end{matrix} \tag{12}$$

After obtaining the vector as shown in equation (12), the cross product of the vector is calculated, if ①③ has the same sign and ②④ has the same sign, then it means that point P collides in the rectangular region determined by the bench in the i-th piece, that is, between the bench and the bench. The value of P point is the coordinates of the four vertices of the faucet bench, as shown in Figure 1(a). T_0 is the end of the inventory, then there are:

$$T_0 = \min\{t \,|\, PV_1^i \times V_1^iV_3^i \neq PV_3^i \times V_1^iV_3^i \text{ or } PV_2^i \times V_2^iV_4^i \neq PV_4^i \times V_2^iV_4^i\} \tag{13}$$

(2) As shown in Figure 1 (b): with the deepening of the dragon dance team, the length of the front and rear handles on the spiral line will not be longer than the length of the front and rear handles on the actual dragon bench, that is, the space is too small to be coiled in again, and it needs to be terminated at this time. The t_0 is the end of the coiling, where the diameter angle of the front handle is $\theta_1(t_0)$ and the diameter angle of the rear handle is $\theta_2(t_0)$. In a very small period of time, the diameter angle of the front handle increases by $\Delta\theta \to 0$. Then the existence of a positive number must be satisfied δ such that:

$$\begin{cases} \Delta\vartheta = \min\{\Delta\theta \,|\, \sqrt{(x_1(\theta_1 + \Delta\theta) - x_2(\theta_1 + \Delta\theta)^2 + (y_1(\theta_1 + \Delta\theta) - y_2(\theta_1 + \Delta\theta)^2} = d_1\} \\ \Delta\vartheta > \delta \end{cases} \tag{14}$$

Or:

$$\begin{cases} \Delta\vartheta = \min\{\Delta\theta \,|\, \sqrt{(x_1(\theta_1 + \Delta\theta) - x_2(\theta_1 + \Delta\theta)^2 + (y_1(\theta_1 + \Delta\theta) - y_2(\theta_1 + \Delta\theta)^2} = d_1\} = \emptyset \\ \Delta\vartheta < \theta_1 - \theta_2 + \Delta\theta \end{cases} \tag{15}$$

3.2 Solving of termination cases

For the solution of this problem, it is difficult to directly obtain the termination time, this paper adopts a variable step size search algorithm, and dynamically adjusts the step size during the search process to solve the termination time, and the algorithm steps are as follows shown in Figure 2:

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

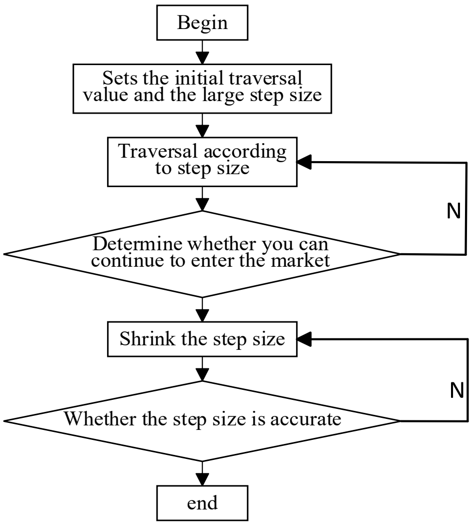


Figure 2 Algorithmic flow

Step1: Initialize and select the big step size. t=300s is selected as the initial time, and $\Delta t = 10$ is selected as the step size.

Step2: Calculate the position of the entire dragon dance team at each moment, determine whether there is a collision or the space is too small to continue to enter, if you can continue to enter, continue to traverse, if not, then Step3 operation.

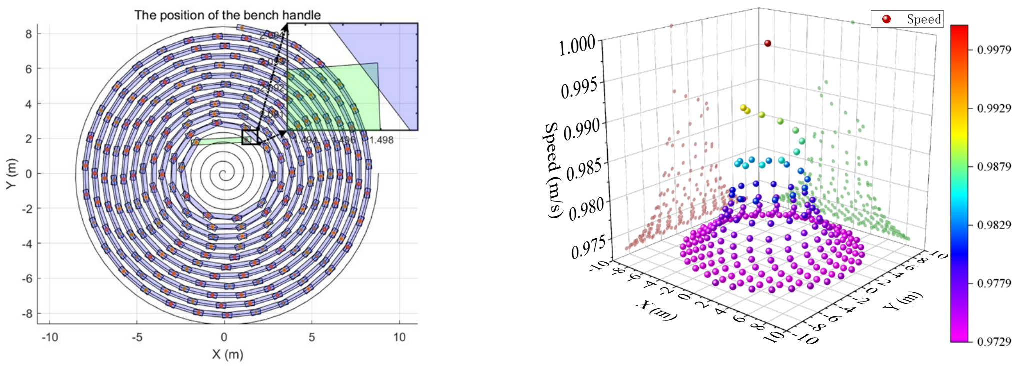
Step3: Shrink the step size and traverse finely. Reduce the step size to one-tenth of the length of the previous step, select the last time of the previous step to continue the disk time as the initial moment, and repeat the operation of Step2.

Finally, when $t = 412.473838$, it is impossible to continue to disk, and the position and speed of the entire dragon dance team at this time are calculated, and some of the results are shown in Table 1.

Table 1 The coordinates and speed of the dragon dance team at the end of the moment

	x (m)	y (m)	Speed (m/s)
Faucet (m/s)	1.231510	-1.927991	1.000000
Section 1 Dragon Body (m/s)	-1.624142	-1.770335	0.991533
Section 51 Dragon Body (m/s)	1.305538	-4.318789	0.976825
Section 101 Dragon Body (m/s)	-0.561594	5.877392	0.974517
Section 151 Dragon Body (m/s)	0.943565	6.960632	0.973575
Section 201 Dragon Body (m/s)	-7.896767	1.205562	0.973063
Dragon's Tail (Rear) (m/s)	0.981468	-8.319528	0.972905

At the end moment, the dragon head collides with the 8th dragon body and cannot continue to coil, as shown in Figure 3(a). At this time, the distance between the front handle of the faucet and the snail is 2.29m. As shown in Figure 3(b), the velocity of all dragon bodies and tails is less than that of the dragon's head, and the further back the dragon body, the smaller the velocity. The speed of the dragon tail is 0.972938m/s, which is 3% different from the speed of the dragon head.



(a) *The position at the end of the disk* (b)*The speed at the end of the disk*

Figure 3 The state of movement of the dragon dance team at the end of the game

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

3.3 Establishment of the minimum disc pitch model

When the turn-around space is a circular area with a diameter of 9m, the front handle of the faucet should be able to enter the turn-around space along the spiral, and the minimum coil pitch should be obtained. Considering that the polar coordinate equation of the spiral is $r = a + b\theta$, the polar diameter decreases monotonically as θ increases. Therefore, there is only one intersection point between the spiral and the U-turn space.

In order to make the front handle of the faucet coil along the corresponding spiral into the boundary of the turning space, it is only necessary to ensure that the pole diameter of the end position of the coil is less than 4.5m when the handle moves along the spiral.

For a given pitch b_0, assume that the moment of collision is $T_0(b_0)$ and the polar diameter is $r_0(b_0)$. The conditions that satisfy the boundary of the faucet front handle that can be coiled into the U-turn space along the corresponding helix are:

$$r_0(b_0) \leq 4.5 \tag{16}$$

Among them:

$$T_0(b_0) = \min\{t | PV_1^i \times V_1^iV_3^i \neq PV_3^i \times V_1^iV_3^i \text{ or } PV_2^i \times V_2^iV_4^i \neq PV_4^i \times V_2^iV_4^i\} \tag{17}$$

Assuming that B is the minimum pitch that satisfies the constraints, we have:

$$B = \min\{b_0 | r_0(b_0) \leq 4.5\} \tag{18}$$

3.4 Solving the minimum disc pitch model

In this paper, the minimum pitch is solved by combining the ergodic method and the dichotomy method, observing the overall trend through the traversal method, and quickly searching for the minimum pitch through the dichotomous method, the algorithm steps are as follows:

Step1: Traverse through different pitches. Select a larger step size, traverse the U-turn space radius under different pitches, observe the approximate trend of the U-turn space radius on the pitch, and select the interval where the U-turn space radius is 4.5m as the initial interval of the dichotomy method for bipartite solving.

Step 2: Calculate the midpoint of the interval. Calculate the U-turn space radius at the midpoint of the interval and determine the area where the minimum pitch is located.

Step 3: Update the interval. Update this area to the next calculation interval, and repeat Step2 iteration with the new interval until the accuracy requirement is satisfied.

The schematic diagram of the algorithm and the solution process are shown in Figure 4.

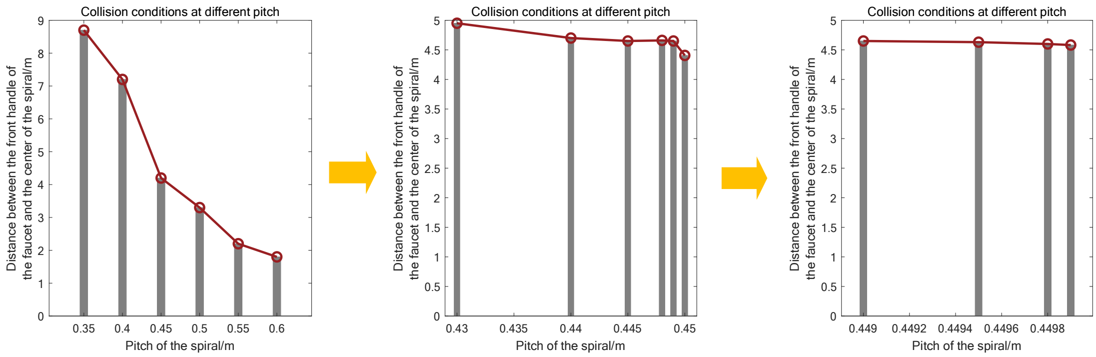


Figure 4 Traversal combined with dichotomous schematic diagram

When the minimum pitch is 0.4500m, the front handle of the faucet can be coiled along the corresponding spiral to the boundary of the U-turn space with a radius of 4.5m. When the pitch is 0.4500m, the position of the entire dragon dance team at the moment of collision is shown in Figure5.

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

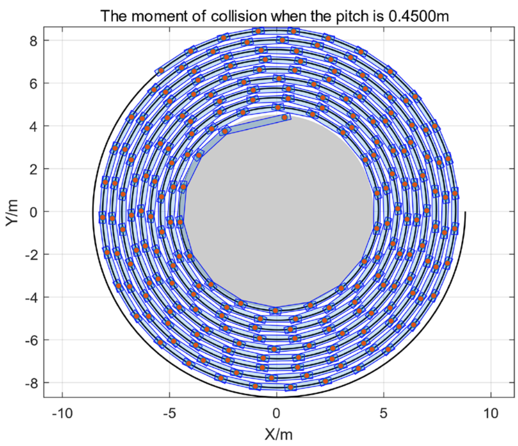


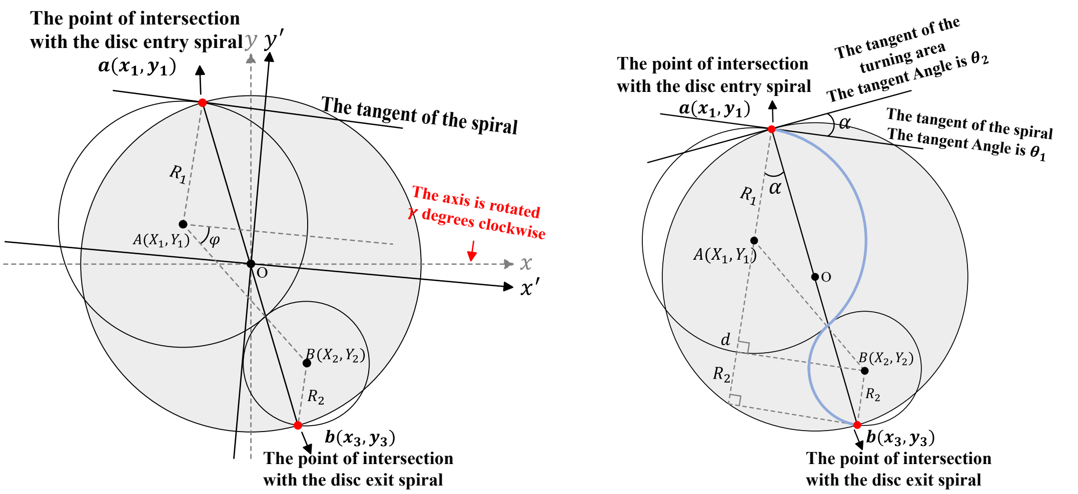
Figure 5 The position of the minimum pitch at the moment of collision

4. Establishment and solution of U-turn curve model

4.1 The turning curve model is established

4.1.1 The relationship between the length of the route and the radius of the U-turn area

The pitch of the inward spiral is 1.7m, and the outward spiral and inward spiral are centrosymmetric about the center of the spiral. If the turning space is a circular area with the center of the spiral as the center of the circle and the diameter of 9m, as shown in Figure 5 (*a*), the turning path is an S-shaped curve formed by the tangent connection of two arcs. It is assumed that the turning head is carried out as soon as the turning head space contacts, and the geometric relationship between the turning curve and the spiral is shown in Figure 6. Since the arc is to be tangent to the spiral, the line between the intersection of the spiral and the arc and the center of the circle is perpendicular to the tangent of the spiral at the intersection, and the two tangent lines are parallel.



(a) Turning curve geometric constraints (b) Turning route length and the relationship between the space radius

Figure 6 Schematic diagram of U-turn route6

Rotate the axis clockwise about the origin degree. Y Assuming that the coordinates of the points in the new coordinate system are$(\overline{x_1},\overline{y_1})$, there are:

$$(\overline{x_1},\overline{y_1}) = (x_1 cos\gamma + y_1 sin\gamma, y_1 cos\gamma - x_1 sin\gamma) \tag{19}$$

The point is symmetric with the point about the origin center of the new coordinate system, then,$b(-\overline{x_1},-\overline{y_1}), A(\overline{x_1},\overline{y_1}-R_1), B(-\overline{x_1},-\overline{y_1}+R_2)$.If two arcs are tangent, then both sides of the equation are squared at the same time, that is:

$$4\overline{x_1}^2 + (2\overline{y_1} - R_1 - R_2)^2 = (R_1 + R_2)^2 \tag{20}$$

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

Set φ as the Angle between the vertical line of the tangent line and the line of the center of the circle, then:

$$\sin\varphi = \frac{2\overline{y_1} - R_1 - R_2}{R_1 + R_2} \tag{21}$$

Since the center angles of the two arcs are the same are $\varphi + 0.5\pi$, then the sum of arc lengths is:

$$L = \left(\varphi + \frac{\pi}{2}\right)(R_1 + R_2) = \left(arcsin\frac{2 \ - R_1 - R_2}{R_1 + R_2} + \frac{\pi}{2}\right)(R_1 + R_2) \tag{22}$$

Since $R_1 + R_2$ is a fixed value, It can be obtained from equation (22) that L is a constant value, that is, when the radius of the turning space is determined, no matter how the ratio of the radius of the two circulars changes, the length of the turning route is a constant value, and it is tangent to the disc in and disc out spiral. A graph can be drawn as shown in Figure 6 (a). Let the oradius R of the circle be, in a right triangle abc we get:

$$R_1 + R_2 + (R_1 + R_2)\sin(0.5\pi - 2\alpha) = 2Rcos\alpha \tag{23}$$

The expression for the length S of the turning circle is:

$$S = (\pi - 2\alpha)(R_1 + R_2) \tag{24}$$

The polar equation of the circle is:

$$r = R \tag{25}$$

The joint vertical (1) (25), the solution of the spiral and circle intersection $a(\frac{R-a}{b}, R)$, then in the xoy coordinate system it is $a(Rcos(\frac{R-a}{b}), Rsin(\frac{R-a}{b}))$. The tangential Angle of the isometric helix at the set point a is θ_1, and the tangential Angle of the circle over the tangent point a is θ_2, then there are:

$$tan\theta_1 = \frac{r'(\theta)sin\theta + r'(\theta)cos\theta}{r'(\theta)cos\theta + r'(\theta)sin\theta} \tag{26}$$

$$tan\theta_2 = -cot\left(\frac{R-a}{b}\right) \tag{27}$$

$r'(\theta)$ denotes the derivative of the spiral equation, the included Angle α can be expressed as:

$$tan\alpha = |tan(\theta_2 - \theta_1)| \tag{28}$$

The relationship of arc length with the radius of the turning area obtained by coupling (23) (24) (26) (27) (28) is as follows (29) :

$$S(R) = \left(\pi - 2arctan\left(\frac{b}{R}\right)\sqrt{R^2 + b^2}\right) \tag{29}$$

As S decreases with the reduction of R, it means that if the radius of the turning space is reduced, the length of the turning route will also decrease accordingly.

4.1.2 Faucet position

Shortening the radius of the turning space will lead to a shorter route, but in the process of shortening, it is necessary to ensure that the dragon dance team has enough space and can not collide, so it is necessary to analyze the movement of the team. Now given the space radius and the proportion of the radius of the two circular arcs, the route is only determined.

4.1.3 Recursion of the position of the dragon body

Set the path to which the i-th handle belongs at time t to $G_i(t)$, its value can be 1,2,3,4.$G_i(t) = 1$ denotes that it is located in the disc entry spiral, $G_i(t) = 2$denotes that it is located in the first arc, and so on.Let's determine which path the i+1 handle is on. If the first handle is located in the first arc, the i+1 handle may be located in the entry spiral or the first arc; The fourth handle is located in the second arc, and the i+1 handle may be located in the second arc or the first arc; The first handle is located in the exit spiral, and the second handle may be located in the second arc or exit spiral. In addition to the spiral, each path has a starting point. To determine which path the i+1 handle is on, only compare the distance between the handle and the i+1 handle and the distance between the handle and the starting point of other paths, which needs to meet:

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

$$\begin{cases}\sqrt{(x_{i+1}(t)-x_i(t))^2+(y_{i+1}(t)-y_i(t))^2} \geq \sqrt{(x_{G_{i+1}(t)}(t)-x_i(t))^2+\left(y_{G_{i+1}(t)}(t)-y_i(t)\right)^2} \\ \sqrt{(x_{i+1}(t)-x_i(t))^2+(y_{i+1}(t)-y_i(t))^2} \geq \sqrt{(x_{G_{i+1}(t)-1}(t)-x_i(t))^2+(y_{G_{i+1}(t)-1}(t)-y_i(t))^2}\end{cases} \quad (30)$$

Let's analyze the relationship satisfied by the coordinates of the *i*+1 point. It is also necessary to discuss the classification of the path of the point. Now analyze the *i*+1 point in the first arc and the *i* point in the second arc. The coordinates are as follows:

$$\begin{cases}\sqrt{(x_{i+1}(t)-x_i(t))^2+(y_{i+1}(t)-y_i(t))^2}=d_i \\ \sqrt{(x_i(t)-X_1)^2+(y_i(t)-Y_1)^2}=R_1\end{cases} \quad (31)$$

According to formula (32) and (33), the $i+1$ handle coordinates can be obtained according to the coordinates of the i handle. The rest is similar.

4.1.4 Recursion of the dragon's body speed

When the two adjacent handles are on the same arc at all t times, they have the same speed, that is:

$$\begin{cases}v_i(t)=v_{i+1}(t), G_i(t)=G_{i+1}(t)=2 \\ v_i(t)=v_{i+1}(t), G_i(t)=G_{i+1}(t)=3\end{cases} \quad (32)$$

When the two adjacent handles are not on the same arc, they also need to be classified. Since the situation on the spiral has been derived in detail, the analysis of the $i+1$ point in the first arc and the i point in the second arc is given here. The two handles have the same velocity component on the line:

$$\left(\overrightarrow{v_i(t)}-\overrightarrow{v_{i+1}(t)}\right)\left(x_i(t)-x_{i+1}(t), y_i(t)-y_{i+1}(t)\right)=0 \quad (33)$$

The velocity components on the axis have the following relation:

$$\frac{y_i(t)-Y_1}{x_i(t)-X_1}=\frac{v_i^y(t)}{v_i^x(t)} \quad (34)$$

4.2 The solution of the turning curve

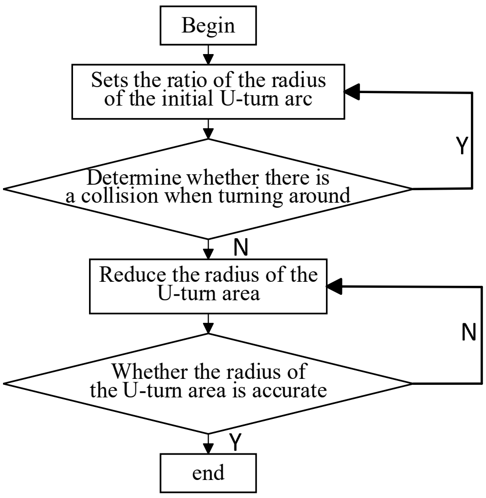


Figure 7 Algorithm flow

The arc can be adjusted to still keep all parts tangent, making the turning curve shorter. If the turning curve starts from the turning space boundary of radius 9m, the length of the turning curve will not change if the ratio of the radii of the two ends of the circular arc is changed according to the geometric derivation above. If we continue to turn in at the turning space boundary and turn around at a certain distance, the turning radius will become smaller, the circular arc will change, and the turning curve will become shorter. According to the relationship between the length of the U-turn curve and the U-turn radius derived above, the smaller the U-turn radius, the shorter the U-turn curve. Therefore, this paper solves the problem of minimum U-turn radius. The algorithm flow is shown in Figure 7.

Step1: Set the ratio of the radius of the arc. Select the appropriate step size to traverse the ratio of the

ISSN 2706-655X Vol. 7, Issue 1: 56-66, DOI: 10.25236/IJFET.2025.070109

radii of the two tangent arcs, and calculate the minimum turning radius under the ratio of each radius.

Step2: Set the traversal turning radius. If the ratio of radius is known, start from 4.5m and gradually reduce the turning radius in a certain step.

Step3: Determine whether there is a collision, if there is no collision, continue to reduce the turning radius, repeat Step2; If there is a collision, stop Step2, the radius of the turning area at the previous time is the minimum turning radius under the radius of this arc, repeat Step1.

The relationship between the ratio of the radius of the turning circle and the radius of the turning area is obtained as shown in Figure 8 below:

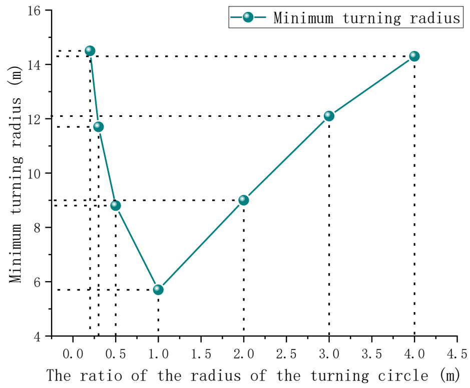


Figure 8 Relation between radius ratio of turning curve and radius of turning area

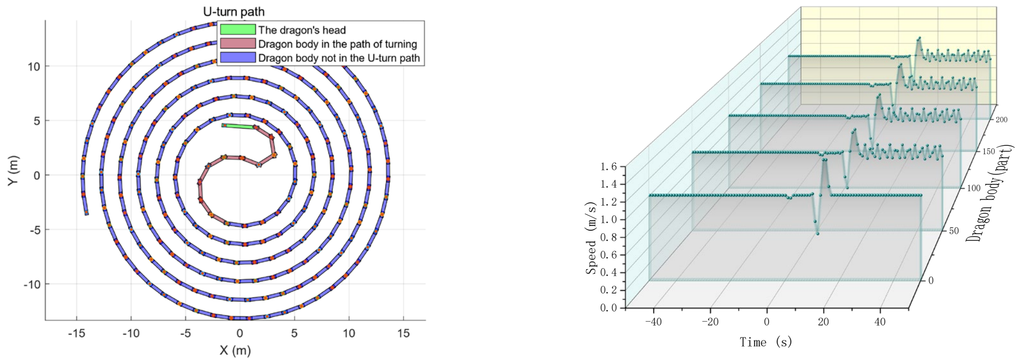
It can be found that when the ratio of radius is reciprocal to each other, the minimum turning radius is the same. And when the ratio of radii is 1:1, the turning path is the shortest. Considering that a too small U-turn radius can make the dragon dance team travel the least distance, but it will be too crowded, this paper chooses the case where the ratio of U-turn radius is 2:1, and the minimum U-turn radius is about 9m, with the time just entering the U-turn path being 0s and the time before entering the U-turn path being <0s. The position and speed of the dragon dance team at different times are shown in Table 2 and Table 3 below:

Table 2 Location information

Location/Time (m)	-100s	-50s	0s	50s	100s
Faucet x	7.778034	6.608301	-2.711856	1.332695	-3.157229
Faucet y	3.717164	1.898865	-3.591078	6.175324	7.548511
Section 1 Dragon Body x	6.209273	5.366911	-0.063534	3.862265	-0.346890
Section 1 Dragon Body y	6.108521	4.475404	-4.670888	4.840828	8.079166
Section 51 Dragon Body x	-10.608038	-3.629945	2.459962	-1.671385	2.095033
Section 51 Dragon Body y	2.831491	-8.963800	-7.778145	-6.076713	4.033787
Episode 101 Dragon Body x	-11.922761	10.125787	3.008493	-7.591816	-7.288774
Section 101 Dragon Body y	-4.802378	-5.972246	10.108539	5.175487	2.063875
Section 151 Dragon Body x	-14.351032	12.974784	-7.002789	-4.605165	9.462514
Section 151 Dragon Body y	-1.980993	-3.810357	10.337482	-10.386988	-3.540357
Section 201 Dragon Body x	-11.952942	10.522509	-6.872842	0.336952	8.524374
Section 201 Dragon Body y	10.566998	-10.807425	12.382609	-13.177610	8.606933
Dragon Tail (rear) x	-1.011059	0.189809	-1.933627	5.859095	-10.980157
Dragon tail (rear) y	-16.527573	15.720588	-14.713128	12.612894	-6.770006

Table 3 Speed information3

Speed/Time (m/s)	-100s	-50s	0s	50s	100s
Faucet	0.999998	0.999988	0.999955	0.999986	0.999998
Section 1 Dragon Body	0.999902	0.999751	0.998128	1.000348	1.000122
Section 51 Dragon Body	0.999345	0.998636	0.994595	0.950403	1.003963
Section 101 Dragon Body	0.999090	0.998244	0.993913	0.948956	1.091533
Section 151 Dragon Body	0.998943	0.998044	0.993622	0.948514	1.090582
Section 201 Dragon Body	0.998848	0.997923	0.993462	0.948300	1.090212
Dragon Tail (rear)	0.998816	0.997883	0.993412	0.948237	1.090112



(*a*) *Dragon team turning curve position(t=20s)* (*b*)*Speed of part of dragon team (-50s,50s)*

Figure 9 Visualization of position and speed information9

Figure 9 (*a*) is a schematic diagram of the position of the dragon dance team changing over time, and the position is shown here. As can be seen from Figure 9 (*b*), when 0-20s, the dragon dance team just entered the turning curve, and the speed changed greatly. For the dragon body close to the dragon body, the speed change is small, for the dragon body that is far away from the dragon body, after turning around, the speed change trend begins to tremble.

5. Conclusions and implications

This paper describes the movement of the dragon dance team through precise mathematical equations and geometric relations, and provides a scientific method to predict and analyze the trajectory of the movement. The method of variable step length and dichotomy are used to solve the problem. At the beginning, use a larger step length to explore quickly, and then gradually reduce the step size, make more fine adjustments, and improve the efficiency and accuracy of convergence. The model allows different dragon team configurations and movement strategies to be verified and tested through computer simulation, which helps to predict possible problems and effects before practical application. It provides a feasible method to study the kinematic state of connectome.

References

[1] Chen L, Liu Y, Zuo T, et al. Teaching Practice of Dragon and Lion Dance in Colleges and Universities with the Support of Big Data Technology[J]. Wireless Communications and Mobile Computing, 2022, 2022(1): 4733795.
[2] Wang N, Yang X, Wang T, et al. Collaborative path planning and task allocation for multiple agricultural machines [J]. Computers and Electronics in Agriculture, 2023, 213: 108218.
[3] Pappalardo C M, Guida D. Dynamic Analysis and Control Design of Kinematically-Driven Multibody Mechanical Systems [J]. Engineering Letters, 2020, 28(4).
[4] Yao W, Yang L, Guo M. Gauss optimization method for the dynamics of unilateral contact of rigid multibody systems [J]. Acta Mechanica Sinica, 2021, 37: 494-506.
[5] Belal A E, Takemori T, Tanaka M, et al. Mobile manipulation using a snake robot in a helical gait. Advance online publication [J]. IEEE/ASME Trans Mechatron, 2021.
[6] Li D, Wang C, Deng H, et al. Motion planning algorithm of a multi-joint snake-like robot based on improved serpenoid curve [J]. IEEE Access, 2020, 8: 8346-8360.
[7] Guo Y, Sun P, Feng X, et al. Adaptive fuzzy sliding mode control for high-speed train using multi-body dynamics model [J]. IET Intelligent Transport Systems, 2023, 17(2): 450-461.
[8] Guoshuang S. A description of the relative motion in the composite motion of a point[J]. Mechanics in Engineering, 2016, 38(2): 181-186.
[9] Zongzhan G A O, Wei L I U, Hangshan G A O, et al. Analysis on the transport motion and proof of the composition theorem for moving points[J]. Mechanics in Engineering, 2022, 44(1): 159-162.
[10] Sanh D. The method of transmission matrix for investigating planar mechanisms[J]. Vietnam Journal of Mechanics, 2007, 29(1): 37-46.