Safety Analysis of the Folk Activity "Bench Dragon" Based on Motion Modeling

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Abstract. The protection of folk culture is not only a respect for history and tradition but also an important measure to promote social development, cultural inheritance, and economic prosperity. This paper focuses on the traditional local folk cultural activity of the "Bench Dragon" found in the Zhejiang and Fujian regions, investigating the most reasonable motion of each segment of the dragon body under specific spatial constraints and dragon body length. We establish corresponding mathematical models for the conditions of the dragon body entering and exiting, as well as collision detection, utilizing Newton's iterative method, the bisection method, and knowledge of plane geometry. Through recursive relationships, this study determine the geometric positions and velocities of each segment of the dragon body at different time points, while geometric relationships help identify the time nodes that avoid collisions during the entering process. Additionally, optimization algorithms are employed to derive the minimum pitch required for the dragon body to safely turn. The research results presented in this paper are significant for the safety and aesthetic appeal of folk activities such as the "Bench Dragon," contributing to the inheritance and promotion of outstanding Chinese folk culture.

Keywords: Bench Dragon, Archimedean Spiral, Newton Iteration Method, Bisection Method.

1. Introduction

The "Bench Dragon" is a traditional folk cultural activity in the Zhejiang and Fujian regions, gradually formed by farmers through long-term observation and practical production activities [1]. This folk activity typically involves dozens to hundreds of benches connected end-to-end by their handles, with the leading bench referred to as the dragon head, the last bench as the dragon tail, and the middle benches as the dragon body, collectively taking the shape of a circular disc. As a unique form of folk culture, the "Bench Dragon" is closely related to China's social management systems, behavioral patterns, and ideologies, making the inheritance of this activity necessary [2]. However, due to the large number of participants, the extensive scale, and the use of hard objects such as benches, the activity is prone to accidents such as collisions and stampedes. To conduct this folk activity more safely, this paper establishes a mathematical model to explore the velocities of each segment of the dragon body from the initial entry to the turning and exiting process, the critical conditions for avoiding collisions, and the minimum pitch needed for safe turning.

Currently, many scholars both domestically and internationally have conducted research on spiral motion. Nuhu Aliyu Shuaibu simulated pedestrian movement at zero delay waiting points to achieve a Tawaf flow with a low probability of congestion and smooth pedestrian flow, proposing a spiral model based on decreasing and increasing path radii. However, the model assumes that all agents have the same speed and behavioral characteristics. In reality, there may be significant differences in pedestrian speed, body size, and behavior, which could lead to discrepancies between the model and actual conditions [3]. Mengwei Guo proposed an improved ant lion optimizer based on a spiral complex path search pattern to enhance population diversity and the algorithm's balance between exploration and exploitation. However, this algorithm failed to optimize discrete engineering problems [4]. Weiqin Sun analyzed the motion characteristics and energy of particles in a tube, showing that the local maxima of the particle distribution function at a given radial distance will arrange into a spiral distribution, determining the positions of particles at different times and the Archimedean spiral equation. However, theoretical models are typically based on a series of simplifying assumptions, which may lead to insufficient descriptions of actual physical phenomena. For example, the model may overlook other important physical processes or interactions, such as collisions between particles and nonlinear effects [5]. Jinhui Huang used vector cross products for line segment intersection collision detection, determining whether two rectangles overlap to assess if a collision occurs. However, it may not accurately handle cases where the rectangle boundaries are in contact, potentially leading to misjudgments in practical applications, such as when two rectangles touch but do not actually collide [6]. QingYing Ge employed collision detection based on the Separating Axis Theorem to detect collisions between vehicles and obstacles. Through simulations and experimental validation, an improved bidirectional RRT intelligent vehicle path planning method was proposed, which can be practically applied on smart electric vehicle platforms. However, this may not effectively handle collisions with dynamic obstacles or moving objects, especially in complex environments, where it may not timely update paths to avoid collisions [7]. Kun Hao proposed an adaptive genetic algorithm based on collision detection, which improves the efficiency of the algorithm's program operation and can be used for mobile robot path planning. However, it is only suitable for global path planning in static environments and does not consider dynamic or unknown environments [8]. YiHeng Zhang employed simulated annealing algorithms to determine the optimal path for the Bench Dragon's movement into the turning space, solving for the minimum pitch and optimal turning path during the spiral motion process [9].

This paper analyzes the motion conditions of the dragon body units and the overall structure in the "Bench Dragon" folk activity, collision conditions, and optimal paths. Starting from the Archimedean spiral motion trajectory, we employ Newton's iterative method to obtain the velocities and positions of each segment of the dragon body; we use the overlap of areas between the dragon head and the dragon body as a criterion for determining collisions; and we apply the bisection method recursively to derive the minimum pitch that allows the dragon head to enter the turning space along the corresponding spiral boundary. Our contributions are as follows: (1) understanding the velocities and positions of each segment of the dragon body; (2) determining collisions using point-to-line distance measurements; (3) establishing the size constraints for the pitch required for overall turning, which ensures that the dragon occupies a smaller footprint while maintaining aesthetic appeal, effectively avoiding safety hazards such as crowding and collisions during the activity. Furthermore, this model can be applied to other folk activities such as dragon and lion dances, crowd management, traffic flow optimization, congestion analysis, area analysis, and multi-drone path planning and speed control.

2. Methodology

2.1. Trajectory and coordinate system setup

During the "Bench Dragon" activity, the dragon dance team often spirals in a clockwise manner at equal intervals. Therefore, the movement trajectory of the dragon dance team can be regarded as an Archimedean spiral. Taking the endpoint of the spiraling in as the origin, with the horizontal axis as the x-axis and the vertical axis as the y-axis, we establish a rectangular coordinate system. The equation of the Archimedean spiral is known to be:

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

Given that the initial radius of the spiral is 0, a = 0 ,we establish a polar coordinate system with θ as the polar angle and r as the radial distance, as shown in Figure 1:

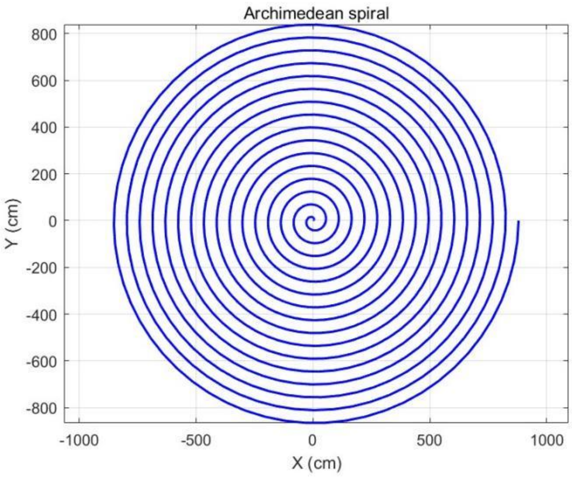

Figure 1. Motion Coordinate System

2.2. Analysis of Spiraling In Motion

2.2.1 Analysis of Dragon Head Motion

The initial position of the dragon head for this activity is set at 16 circles, with the polar angle of the dragon head being , the rectangular coordinates being (8.8m, 0m), and the polar coordinates being (8.8m, 32m). The motion equation for the dragon head is:

$$r_0(t) = b\big(32\pi - \theta(t)\big) \tag{2}$$

According to the calculation formula for the arc length (S) of the Archimedean spiral, we obtain:

$$ds = \int \sqrt{(b\theta)^2 + b^2}\, d\theta = \int b\sqrt{\theta^2 + 1} d\theta \tag{3}$$

Let the linear velocity of the dragon head be v , then the arc length(S_0)traversed by the dragon head is represented as:

$$\begin{cases} S_0(\theta) = S(32\pi) - S(32\pi - \theta) \\ S_0(t) = vt \end{cases} \tag{4}$$

By converting between polar coordinates and rectangular coordinates, the rectangular coordinates of the dragon head are obtained as (x_0, y_0):

$$\begin{cases} x_0(t) = r_0(t)\cos(\theta(t)) \\ y_0(t) = -r_0(t)\sin(\theta(t)) \end{cases} \tag{5}$$

2.2.2 Analysis of Dragon Body Motion

Establish the relationship between the first section of the dragon body and the dragon head, as shown in Figure 2.

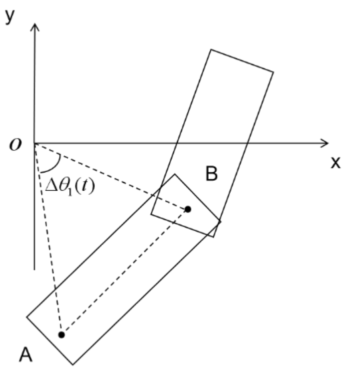

Figure 2. Relationship Diagram of the Dragon Head and Dragon Body

Based on the analysis of the dragon head motion and the trajectory of the Archimedean spiral, the position of the front handle of the first section of the dragon body can be expressed as:

$$\begin{cases} \theta_1(t) = \theta_0(t) - \Delta\theta_1(t) \\ r_1(t) = b(32\pi - \theta(t) + \Delta\theta_1(t)) \end{cases} \tag{6}$$

In triangle OAB, $\cos\Delta\theta_1(t)$, $\Delta\theta_1(t)$, $r_1(t)$ can be approximated as . By combining the above formulas, the rectangular coordinates can be obtained. Since the distance between the front handles of each section of the dragon body is fixed, referring to the position algorithm of the first section of the dragon body, the position of the i-th section of the dragon body can be determined, and the iterative formula can be listed. The mathematical model for the positions of the front handles of each dragon body section can be expressed as:he BP neural network is linked by different node coefficients. When connecting weights and weights are positive, it indicates that the current link is an exciting state. Conversely, if the link coefficient is negative, the link state is a state of suppression.

$$\begin{cases} \cos\Delta\theta_i(t) = \dfrac{r_{i-1}^2(t) + r_i^2(t) - l^2}{2r_{i-1}(t)r_i(t)} \\ r_i(t) = b(32\pi - \theta(t) + \Delta\theta_1(t) + \cdots \Delta\theta_i(t)) \end{cases} \tag{7}$$

Given the position of each section of the dragon body at any moment, the distance between the front handles of two adjacent sections can be expressed using the distance formula between two points. Assuming the adjacent trajectories are approximated as straight lines, the velocity of the i-th point can be expressed as: $v_i = \dfrac{\Delta S}{\Delta t}$. Subsequent calculations can be performed using Newton's iteration method for analysis.

2.3. Dragon Head Collision Analysis

The dragon dance team moves along the aforementioned spiral path, and at the moment of completion, the dragon head will collide with the dragon tail, as shown in the figure.

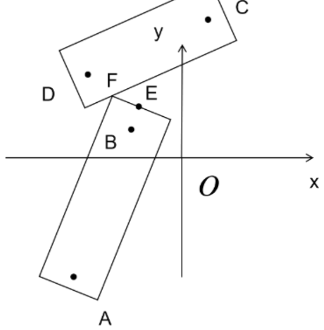

Figure 3. Collision Schematic Diagram

To prevent collisions between the benches and ensure the safe completion of the winding process, this paper uses geometric analysis of the straight-line distance from the dragon head vertex to the center of the dragon body bench for collision detection.

According to the previous analysis, after a time t, the coordinates of points A and B are respectively:

$$\begin{cases} x_1(t) = r_1(t)\cos\theta(t) - \Delta\theta_1(t) \\ y_1(t) = -r_1(t)\sin\theta(t) - \Delta\theta_1(t) \end{cases} \tag{8}$$

$$\begin{cases} x_0(t) = r_0(t)\cos\theta(t) \\ y_0(t) = -r_0(t)\sin\theta(t) \end{cases} \tag{9}$$

The equation of the line AB can be expressed as:

$$\begin{cases} y - y_0 = k(x - x_0) \\ k = \dfrac{y_1 - y_0}{x_1 - x_0} \end{cases} \tag{10}$$

The coordinates of point E can be obtained based on the line equation and the distance from the point to the line:

$$\begin{cases} y_e - y_0 = \dfrac{y_1 - y_0}{x_1 - x_0}(x_e - x_0) \\ (y_e - y_0)^2 + (x_e - x_0)^2 = d_{BE}{}^2 \end{cases} \tag{11}$$

According to the relationship of the slopes of perpendicular line segments, we have $k_{ef}k_{be} = -1$, and similarly, we can derive the equation of line EF, leading to the coordinates of point F:

$$\begin{cases} y_f - y_e = \dfrac{x_0 - x_1}{y_1 - y_0}(x_f - x_e) \\ (y_f - y_e)^2 + (x_f - x_e)^2 = 15^2 \end{cases} \tag{12}$$

Let the dragon head collide with the m-th section of the dragon body. It is evident that at a constant time, the polar angles of the front handle of the dragon body and the front handle of the dragon head differ by 2π. Therefore, the coordinates of the front handle of the m-th section of the dragon body are:

$$\begin{cases} x_m(t) = r_m\cos(\theta(t) + 2\pi) \\ y_m(t) = -r_m\sin(\theta(t) + 2\pi\} \\ r_m(t) = b(32\pi - \theta(t) + 2\pi) \end{cases} \tag{13}$$

Assuming that the distance between the handles DC of the dragon body can be approximated as the arc length between points C and D, we can obtain:

$$\Delta S_{cd} = S_d(\theta) - S_c(\theta - \Delta\theta) \approx d_{CD} \tag{14}$$

This allows us to calculate the polar angle difference between points C and D, and determine the position coordinates of the rear handle of the m-th section of the dragon body. Given the coordinates of points C and D, we can obtain the linear expression for line CD:

$$\begin{cases} y - y_m = k_{cd}(x - x_m) \\ k_{cd} = \dfrac{y_{m+1} - y_m}{x_{m+1} - x_m} \end{cases} \tag{15}$$

When the dragon head collides with the m-th section of the dragon body, the distance from point F to the boundary of the dragon body is extremely small, resulting in $l_{fcd} - \frac{1}{2}d_{dk} \leq 1$. According to the distance formula from a point to a line, substituting the line equation of CD and the coordinates of point F into the formula gives the distance l_{fcd} from F to CD, that is, the collision detection condition is:

$$l\frac{\left|\dfrac{y_{m+1} - y_m}{x_{m+1} - x_m}x_f - y_f - \dfrac{y_{m+1} - y_m}{x_{m+1} - x_m}x_m\right|}{\sqrt{\left(\dfrac{y_{m+1} - y_m}{x_{m+1} - x_m}\right)^2 + 1}} - \frac{1}{2}d_{dk} \leq 1 \tag{16}$$

3. Results and discussion

3.1. Motion position and velocity

In this scenario, let the pitch $p = 55cm$, $b = \frac{p}{2\pi}$, $l_{AB} = 256cm$,and the length of the bench $l = 165cm$, $v = 100cm/s$. Applying the model from problem one, the Newton iteration method [10] is used for recursive calculation. This algorithm has the advantages of fast convergence speed, relative simplicity, and ease of implementation. The positions and velocities of the front handle of the dragon head, the front handles of the 1st, 51st, 101st, 151st, and 201st sections of the dragon body, and the rear handle of the dragon tail at 0 s and 300 s can be obtained, as shown in Table 1:

Table.1. The position and velocity of the bench dragon

Time	Parameter	Head	1st	51st	101st	151st	201st	Tail
0s	x(m)	8.8	8.363824	-9.293445	10.219689	11.135716	12.034295	-5.729062
	y(m)	0	2.826544	-2.594577	2.271785	-1.856825	1.349992	11.076852
	v(m/s)	1	0.9999723	0.9907322	0.964087	0.920039	0.8585882	0.8260365
300s	x(m)	4.420274	2.459489	1.836263	-7.011447	8.928735	-4.834524	5.652915
	y(m)	2.320429	4.402476	-6.222326	3.709795	2.865172	-9.682057	-9.966074
	v(m/s)	1	0.9997115	0.9115569	0.6574876	0.2375192	0.3483537	0.258697

From Table 1, it can be seen that at the initial moment, the speeds of each section of the bench are very similar, and the entire system can be regarded as rigid body motion. As time increases, the speed of the benches further away from the dragon head decreases more rapidly, and by 300 seconds, the speed difference between the dragon tail and the dragon head becomes significant.

3.2. Position and velocity at the moment of collision

Let the time range from the start to the moment of collision be $300s < t < 450s$. According to the collision detection geometric model established in Problem 2, using a step size of t = 1 and substituting into the detection conditions, the final collision time is determined to be 431 s. At this time, the positions and velocities of the front handles of the 1st, 51st, 101st, 151st, and 201st sections of the dragon body, as well as the rear handle of the dragon tail, are shown in Table 2:

Table.2. Bench dragon position and velocity at collision

	x (m)	y (m)	v (m/s)
Head	-1.277560605	-0.605382238	1
1st	1.575664	-0.40863	0.822211234
51st	4.851117	4.572127	0.968048614
101st	-2.783196	11.372906	0.892244568
151st	-16.117846	4.561394	0.842910576
201st	-15.505192	-15.314468	0.608070419
Tail	-23.605623	3.809235	0.652066737

3.3. Overall Analysis and Improvement Plan

The calculation results indicate that, due to the increasing speed differences among the sections of the bench dragon during movement, the speed variations in the rear sections of the dragon body become significant. This may lead to a lack of coordination in the overall movement of the bench dragon, causing some participants to lose their balance and potentially fall or collide. If the distance between the dragon head and the dragon tail is too great, it may result in participants at the back being unable to see the dynamics at the front, preventing them from reacting in time. To enhance safety during the performance, the speeds of the first few sections of the dragon body can be manually controlled and appropriately reduced. This ensures that the speed of the sections behind, which have unclear visibility, remains largely constant throughout, significantly reducing safety risks.

When the dragon head reaches the final moments of movement, the limited space may cause it to collide with the dragon body. To avoid such dangerous incidents, sufficient turning space can be calculated in advance, ensuring that the dragon head does not collide with the dragon body before entering the turning space, thus allowing the folk activity to proceed normally.

4. Conclusion

This article establishes a mathematical model for the general movement of the bench dragon in folk activities, ensuring that the performance occupies a small area while maintaining good visibility, effectively avoiding safety hazards such as crowding and collisions during the event. To prevent dangerous accidents, the speeds of the first few sections of the dragon body can be controlled manually, and sufficient turning space can be reserved to ensure the balance and safety of the bench dragon's movement.

However, there are certain limitations in the model established in this article. The approach taken approximates the arc length traveled by adjacent sections of the dragon body as the corresponding length of the bench, based on the idea of transforming curves into straight lines. As the polar angle increases, the error between the two will also increase relatively, leading to certain inaccuracies. We will further improve upon these limitations to reduce the errors identified in this study.

The proposed movement model and collision analysis model for the bench dragon can be applied to traditional activities such as dragon and lion dances, allowing for the design of complex movement patterns that enhance aesthetics. Additionally, it can be applied to circular incense coils, using this model to study their burning rates and design the width of the incense based on combustion patterns. Furthermore, it can be utilized in areas such as managing crowds with complex movement shapes, traffic flow, congestion analysis, area analysis, multi-drone path planning, and speed control, demonstrating robustness and versatility.

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