Dynamic Simulation and Optimization Analysis of The Bench Dragon Performance

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Abstract. The Bench Dragon is a traditional folk activity from southeastern Zhejiang and Fujian, originating from the Han Dynasty's "dragon dance for rain" ritual. It holds significant cultural value and visual appeal, with performers linking dozens or hundreds of benches into a sinuous dragon shape that requires precise coordination of movement paths and speeds to avoid collisions.This article integrates numerical integration methods with kinematic modeling constraint optimization to construct a mathematical model of the Bench Dragon's performance. Through the Newton-Raphson method and global search, the calculation accuracy and efficiency are improved, and collision detection is carried out to prevent performance accidents. The research results provide scientific support for the highly difficult performances of the bench dragon and are conducive to the inheritance of traditional culture and the improvement of the viewing experience.

Keywords: Bench Dragon, Newton-Raphson method, collision detection, traditional culture.

1. Introduction

The "bench dragon" is a traditional folk cultural activity in the southeastern regions of Zhejiang and Fujian provinces in China, also known as the "circling dragon". It constitutes a significant annual event in the cities of southern China. This Lantern Festival custom has been passed down for several centuries. It holds a prominent position in the folk dance culture of Zhejiang Province and preserves the traditional folk culture characterized by people's belief in dragons, particularly in the coastal and southern areas of Zhejiang provinces. This type of dragon dance is reputed to have originated in the Han Dynasty [1-2]. It emerged from a religious activity called "dancing with a dragon to seek rain". It is said that a long time ago, there was a severe drought. A water dragon from the East Sea emerged from the water regardless. It brought a heavy downpour. However, the water dragon violated the rules of heaven and was cut into pieces and cast to the human world. People placed the dragon body on benches and connected them. They were called 'bench dragons'. As a traditional folk activity in China, the bench dragon has a rich historical and cultural background as well as unique artistic charm. Its cultural value in contemporary society is not only reflected in the inheritance of local culture, but also in enhancing community cohesion, protecting intangible cultural heritage and promoting cultural tourism. Facing the rapid development of modern technology, the bench dragon has huge potential for development. Through digital preservation, the combination of innovation and modern technology, the integration of cultural education, and environmental protection and sustainable development, the bench dragon can regain new vitality in the new era background.

Performers link dozens or even hundreds of benches end to end to form a sinuous and twisting dragon shape. Under the leadership of the dragon head, the dragon body and tail encircle each other, resembling a round plate. It is highly enjoyable to watch. Fig. 1 shows the front view of the Bench Dragon.

Fig.1 The front view of the Bench Dragon

Such a large-scale performance is extremely challenging to execute. The difficulty of the bench dragon performance lies in successfully spiraling in and out along the Archimedean spiral with hundreds of benches connected. If one part of the dragon body makes an error, every subsequent part will be affected. Simultaneously, it is necessary to avoid collisions between the benches used by the performers to prevent danger. Hence, it is of great significance to simulate the overall movement track of the bench dragon and coordinate the movement speeds of each dragon handle.

The common solutions to the problem of path planning and multi-object motion simulation are numerical integration method and kinematic modeling constraint optimization. The methods of numerical integral simulation of motion trajectory include Euler method[3] and Runge-Kutta[4-5] method.The Euler Method is simple and rapid, yet it possesses significant errors that might accumulate and render the simulation results unstable. The Runge-Kutta Method is more stable and precise, but its calculation cost is higher. Due to the large number of benches in this context, the Euler Method is employed for simulation in this paper. To simulate and calculate the coordinates and movement speeds of the bench dragon handle at each moment, the bisection method can frequently be utilized. However, the bisection method employs linear convergence, with a relatively slower convergence speed. Therefore, the Newton-Raphson method[6-8] is adopted for iteration in this paper. The Newton-Raphson method features a fast convergence rate and high precision, which can significantly reduce the calculation cost and enhance the calculation speed. However, if only the numerical integration algorithm is used, it can not adapt to the model well when the dynamic behavior of Benbenlong changes dramatically, and large deviations will be generated.

The method of kinematic modeling constraint optimization can carry out global search to find a better global solution, especially in terms of optimization path and speed, and can handle complex multi-objective optimization problems. However, some common algorithms, such as particle swarm optimization[9], require a large amount of computing resources and the relevant parameters need to be fine-adjusted, otherwise the convergence will be slow.

In this article, numerical integration method and kinematic modeling constraint optimization are comprehensively used, successfully constructed a mathematical model during the bench dragon performance process. It simulated the movement paths of each handle of the bench dragon under specific conditions and the movement speeds of each handle at the corresponding time. It further analyzed the optimal performance plan for the bench dragon to spiral in and out successfully without any collisions. This method is suitable for any short step spiral trajectory simulation, with high accuracy and strong anti-interference ability. According to the results obtained, it can better help the performers to interpret the performance of the bench dragon, make the viewing better, and better inherit this folk culture.

2. Problem Formulation

Based on the best viewing problem of Bench dragon performance, we propose and solve the following three Research Questions (RQs):

RQ1. The dragon dance team rotates clockwise along an isometric spiral with a pitch of $55cm$, and the center of each handle is located on the spiral. The travel speed of the front handle of the head is always maintained at $1m/s$. Initially, the dragon head is located at point A of the 16th circle of the spiral as shown in Fig.2. Figure out the position and speed of the entire dragon team per second from the initial moment to 300 seconds.

RQ2. On the basis of RQ1, determine the final time to stop the disc is determined so that the collision between the benches of the Dragon team is avoided.

RQ3. From the process of circling into to circling out, the dragon dance team will switch from clockwise to counterclockwise to turn out, which requires a certain space for turning around. If the turning space is a circular area with a diameter of 9 m at the center of the spiral as shown in Fig3, determine the minimum pitch so that the front handle of the dragon head can spiral along the corresponding spiral into the boundary of the turning space.

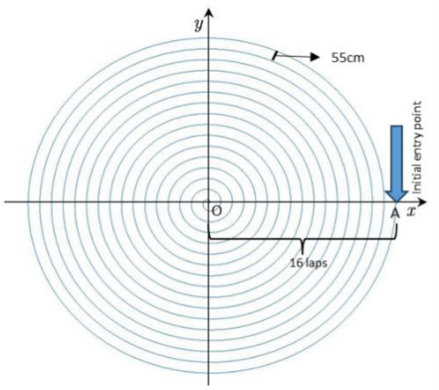

Fig.2 Spiral entry diagram

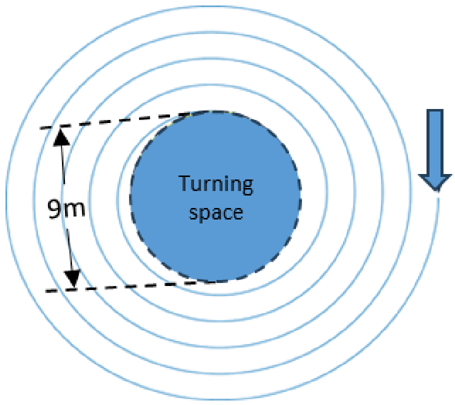

Fig.3 Diagram of turning space

Based on the RQs, the main contributions of this article are.

a. The trajectory model is established, Euler iteration method and Newton iteration method are used to solve the trajectory, and the different states of each position and time of the dragon dance team are successfully simulated.

b. Consider the situation of the dragon dance team circling into the collision, establish a two-dimensional plane model, and use the plane vector method to calculate the final moment of collision, so as to avoid the collision.

c. Use the global search algorithm to calculate the minimum pitch that can make the dragon dance team successfully hover out, so that under the same personnel configuration, the bench dragon performance can achieve the best viewing effect.

3. Methodology

3.1. The model of the bench dragon's spiraling in

RQ1 wants to give the speed and position of the entire dragon team per second between the initial and 300 seconds. When establishing the model, the traveling speed of the head handle is always 1m/s as the constraint condition, according to the equation of the Archimedes helix [10] in polar coordinate system and the formation principle of the Archimedes helix, the differential equation expression of the connection between the head handle and the rotating center point O and the Angle between the positive direction of the axis is derived.

$$\frac{d\theta}{dt}=\frac{1}{b\sqrt{1+\theta^2}} \tag{1}$$

Here, b represents the helical growth rate, and θ is the rotated angle.

The head of a dragon is driven in from the 16th circle of the spiral, and the initial value of the included Angle is obtained. Then the change of the Angle corresponding to the front handle of the head of dragon at every moment is obtained iteratively by Euler method. Since the benches are connected in pairs, the front handles of the two adjacent benches are the front and back handles of the same benches. According to the geometric principle, the cosine theorem can be further applied to list the relation between the Angle corresponding to the front handle of the first dragon body and the front handle of the dragon body.

$$\cos(\theta_i - \theta_j) = \frac{r_i^2 + r_j^2 - d^2}{2r_i r_j} = \frac{b^2\theta_i^2 + b^2 + \theta_j^2 - d^2}{2b^2\theta_i\theta_j} \tag{2}$$

Let r represent the radial distance, d denote the distance between two adjacent front handles, the subscript j indicate the previous bench, and the subscript i represent the subsequent bench.

Transform equation (2) into the form of $f(\theta_i)$, apply the Newton-Raphson method, select an initial value θ_{i0} as the solution of the equation regarding $f(\theta_i)$, and use the relevant iterative formula:

$$\theta_{n+1} = \theta_n - \frac{f(\theta_n)}{f'(\theta_n)} \tag{3}$$

According to the relation, the Angle at every moment of the front handle of each dragon body is obtained. Since the size of the dragon tail and the dragon body are exactly the same, another dragon body can be artificially added as the dragon tail, and the rear handle of the dragon tail can be directly represented by the front handle of the dragon tail when it is not added. After the Angle is obtained, the polar coordinate system of Archimedes helix is transformed into rectangular coordinate system:

$$\begin{cases} x_h = r_h \cdot \cos\theta_h = b \cdot \theta_h \cdot \cos\theta_h \\ y_h = r_h \cdot \sin\theta_h = b \cdot \theta_h \cdot \sin\theta_h \end{cases} \tag{4}$$

Here, x_h represents the x-coordinate of the (h +1)-th bench, y_h represents the y-coordinate of the (h +1)-th bench, and θ_h represents the angle of the (h +1)-th bench, with $h \in (0, 222)$.

Finally, when the central difference method [11] is used to calculate the velocity at the (h+1) th time step, the expression can be written as:

$$v_t^h = \frac{\sqrt{(x_{t+1}^h - x_{t-1}^h) + (y_{t+1}^h - y_{t-1}^h)}}{2\Delta t} \tag{5}$$

Ultimately, the speed of the entire dragon dance team every second during the period from the beginning to 300 seconds can be simulated.

3.2. Collision detection model

This part of this purpose aims to solve the problem involved in RQ2, which is to find the maximum stopping time under the constraint that there is no collision between the benches. Establish a collision detection model: Consider the case of bench collision first, because the dragon dance team enters the inner disc, the first collision is the collision between the dragon head and the dragon body in the outer circle. As shown in Figure 4:

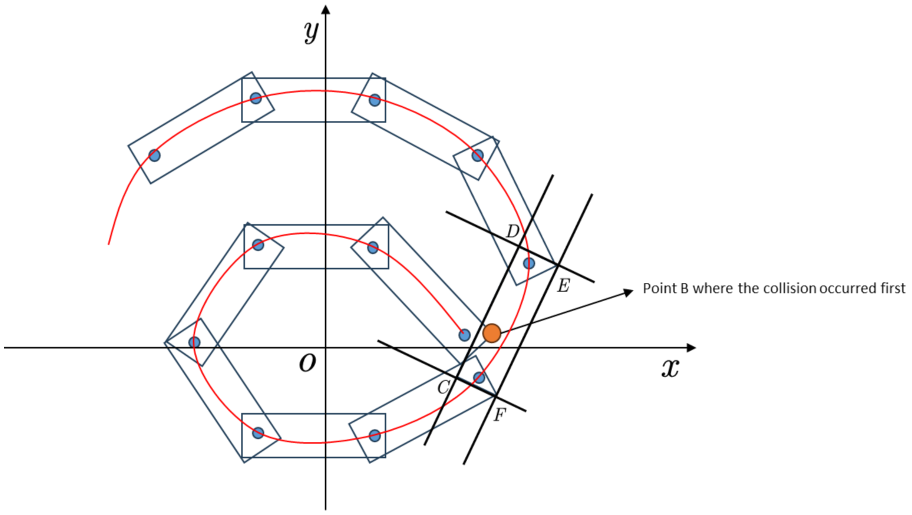

Fig.4 Diagram of the collision occurrence

It can be seen from the figure that the critical condition for the collision between the benches is the moment when the straight lines of the two points B, C and D are just collinear. On the basis of RQ1 we have been able to find the coordinates of a front handle at any time. It means that we can find the equation of a line with two adjacent front handles.

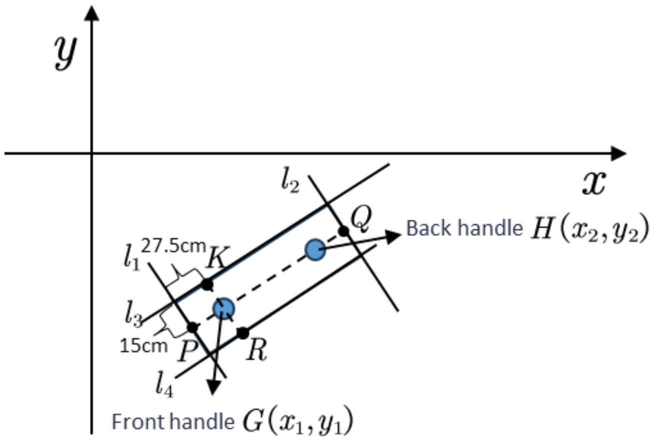

Fig.5 Simple Analytical Diagram of Analytic Geometry

Given that the center of the hole is 27.5cm away from the nearest plate head and the width of the plate is 30cm, he equation of the line where CD is located can be further obtained according to the spatial analytic geometry, similarly: The equation of the line where DE, EF and CF are located can be obtained.

Take l_1 as an example. The equation for l_1 is as follows:

$$y_{l1} - y_P = -\frac{1}{k_{gh}}(x_{l1} - x_P) \tag{6}$$

When the two lines intersect, the coordinates of C and D can be obtained. When comparing whether $\overrightarrow{CB}$ and $\overrightarrow{BD}$ are parallel, the maximum stopping time to avoid collision between benches can be obtained as 412s.

3.3. Minimum pitch model

RQ3 requires finding the minimum pitch so that the front handle of the head of a dragon can be rotated along the corresponding spiral into the boundary of the turning space. Because the turning space is a circular area, the instant when the knob is in front of the head of a dragon, it is considered that the head of a dragon is tangent to the turning space, and the analytic geometric model is established to obtain the constraint condition of the pitch p.

$$\frac{p\theta}{2\pi}=4.5 \tag{7}$$

Find the minimum pitch that can be scaled down with a step size of 0.001 based on the 0.55m given by the RQ1. What needs to be considered is that the head of a dragon cannot collide before it is turned into the boundary of the turning space. Therefore, two states can be set, state 1 is that the front handle of the head of dragon successfully spiral into the turning space boundary, state 2 is that a collision occurred. If either of the two states is achieved, the operation after this pitch p stops, and the above process is repeated after changing the pitch p, traversing the entire range. And when state 1 is reached, output the current value; Conversely, when state 2 is reached, the value at this time is discarded.

The final solution for the minimum pitch p that meets the conditions is 0.450m.

4. Result analysis and discussions

In this section, we present the simulation results of the spiral model of the dragon dance performance concerning three issues. The aim is to simulate the position and velocity of the dragon dance at various time periods, calculate the minimum pitch required for the dragon dance to successfully spiral out without collision, and thereby achieve the best viewing effect.

Table.1 Location result

	0s	**60 s**	**120 s**	**180 s**	**240 s**	**300 s**
Dragon head x (m)	8.800000	5.804436	-4.071678	-2.987236	2.629860	4.394572
Dragon head y (m)	0.000000	-5.765946	-6.313238	6.083611	-5.340109	2.370833
1-seg body x (m)	8.363824	7.459898	-1.429951	-5.254055	4.844796	2.410437
1-seg body y (m)	2.826544	-3.433771	-7.409082	4.339727	-3.530784	4.430640
51-seg body x (m)	-9.518732	-8.688440	-5.555204	2.866289	6.001372	-6.306307
51-seg body y (m)	1.341137	2.533089	6.367667	7.259193	-3.795079	0.409555
101-seg body x (m)	2.913983	5.693127	5.374934	1.924318	-4.886667	-6.268217
101-seg body y (m)	-9.918311	-7.997188	-7.548585	-8.466123	-6.403956	3.888531
151-seg body x (m)	10.861726	6.676685	2.373410	0.979222	2.928694	7.011227
151-seg body y (m)	1.828754	8.139242	9.731310	9.427723	8.412987	4.441077
201-seg body x (m)	4.555102	-6.625606	-10.629337	-9.277041	-7.432475	-7.426452
201-seg body y (m)	10.725118	9.021280	1.344158	-4.270485	-6.210927	-5.309664
Dragon tail x (m)	-5.305444	7.370211	10.973249	7.365440	3.204242	1.729731
Dragon tail y (m)	-10.676584	-8.793329	0.859267	7.510819	9.482215	9.312137

Table.2 Speed result

	0s	60 s	120 s	180 s	240 s	300 s
Dragon head (m/s)	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
1-seg body (m/s)	1.000000	0.999798	0.999765	0.999691	0.999561	0.999284
51-seg body (m/s)	1.000000	0.999503	0.999366	0.999114	0.998660	0.997663
101-seg body (m/s)	1.000000	0.999297	0.999100	0.998758	0.998163	0.996912
151-seg body (m/s)	1.000000	0.999145	0.998911	0.998518	0.997846	0.996477
201-seg body (m/s)	1.000000	0.999027	0.998769	0.998344	0.997629	0.996196
Dragon tail (m/s)	1.000000	0.998984	0.998718	0.998285	0.997551	0.996102

Table.1 and Table.2 record the locations and speeds of some of the benches of the dragon bench during its circling process when the speed of the dragon's head is constant, verifying the authenticity of the model.

Fig.6 depicts the simulation diagram when the dragon dance team collides. Table.3 records the speeds and locations of the dragon head, dragon tail and some parts of the dragon body when the collision occurs. The collision detection model has been successfully established. It is simulated that the termination moment of the dragon dance team's circling in is 412s, which can effectively avoid collision accidents and injuries during the bench dragon performance.

Table.3 Location and velocity at termination

	horizontal coordinate x (m)	vertical coordinate y (m)	speed (m/s)
Dragon head	0.762174	2.178564	0.999569
1-seg body	-1.985813	1.385996	0.991452
51-seg body	0.801649	4.450273	0.977063
101-seg body	-0.043072	-5.911705	0.974776
151-seg body	1.456200	-6.878306	0.973845
201-seg body	-7.807424	-1.716772	0.973333
Dragon tail	0.465020	8.369733	0.973194

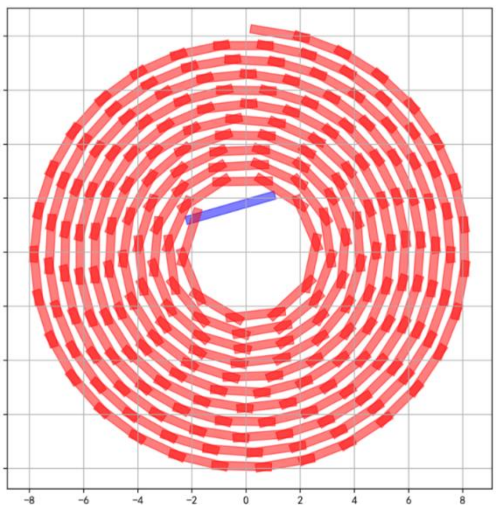

Fig.6 Collision schematic diagram

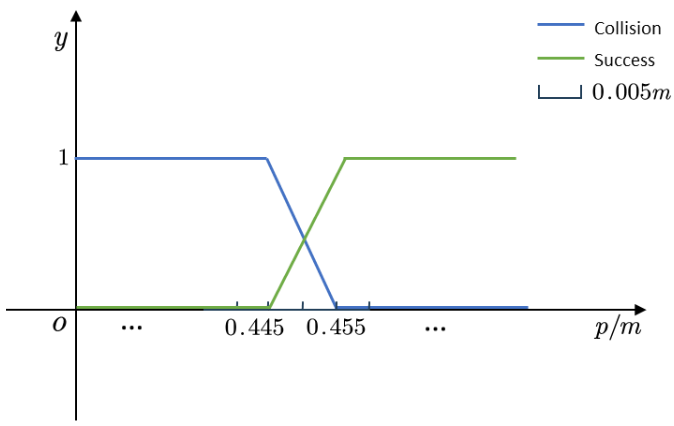

Fig.7 Trigger state diagram

Table.4 Detailed Status Judgment

Pitch $p(m)$	0.446	0.447	0.448	0.449	0.450	0.451	0.452	0.453	0.454
Success	0	0	0	0	1	1	1	1	1
Collision	1	1	1	1	0	0	0	0	0

The trigger status judgment diagram is shown in the Fig.7. According to the data in the Fig.7 and Table.4, it can be seen that when the pitch is 0.450m, the dragon head successfully reaches the turning boundary without collision, which means that at this pitch, the dragon dance performance can be successfully performed without collision, and at this time, the performance area is the smallest and the viewing effect is the best.

5. Conclusions

This research successfully derived the mathematical model of the "bench dragon performance" helix line given the speed of the dragon head, which is used to describe the speed and position of each handle during the performance. It also successfully simulated the critical situation of collision and calculated the minimum pitch required for the dragon dance team to successfully spiral in and out, achieving the smallest performance area and the best viewing effect. This model is suitable for all performances in the form of a helix, which can better protect and inherit traditional culture. The disadvantage is that the model is more ideal, ignoring the effects of wind speed, friction, etc., these external effects can be further considered in the future, so that the model has stronger anti-interference ability.

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