Collision Analysis and Optimization of the "Bench Loong" Model

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Abstract. The traditional folklore activity of Bench Loong is an excellent spectacle, but it is necessary to ensure that the loong can be freely coiled in and out to avoid collision. The extant theories are deficient in that they lack a mathematical analysis of the collision problem of the Bench Loong in motion. This paper presents a dynamic simulation of the basic motion process of the Bench Loong, followed by a geometric analysis of specific collision scenarios based on the shape of the bench and the motion process. This analysis leads to the establishment of a collision analysis criterion, which is then applied to the specific process of the Bench Loong to determine its termination time and state. Although the model is idealized to a certain extent, it is nevertheless highly accurate and provides a reference for the design of the coiling path of the Bench Loong, which is of great value and significance for the inheritance and promotion of traditional culture.

Keywords: Collision Analysis Criterion, Isometric Solenoid, Dynamic Simulation.

1. Introduction

The Bench Loong is a traditional folkloric activity that is prevalent in the Zhejiang and Fujian regions. It is a movement in which benches are joined together to create a shape that resembles that of a loong [1-3]. When the loong is coiled, the cephalic region of the loong is situated in the anterior position, with the trunk and tail following in a coiled circle, forming a disk-shaped structure. The smaller the area required for a coiled loong and the faster it travels, the better the viewing. A collision between the benches during the disk-in process is a significant issue affecting the safety and spectacle of the sport. In light of the growing recognition of the importance of safeguarding intangible cultural heritage, there is an urgent need to enhance the scientific management and optimization of the Bench Loong movement.

However, in the current research context of this model, only some of the studies mentioned how to calculate the displacement and instantaneous velocity of each node corresponding to different moments when the Bench Loong model is running according to the established trajectory, while there is a relative lack of research content on the collision analysis of this model. Based on this, this paper carries out an in-depth study on the collision of the Bench Loong model in the running process and gives relevant results and conclusions.

The most common motion path observed in the Bench Loong is in closest proximity to the isometric solenoid. Despite the extensive theoretical discourse surrounding the isometric solenoid, there remains a paucity of empirical research investigating its practical applications, particularly in the context of traditional folklore practices such as the Bench Loong. Based on the previous research on isometric solenoids, this paper further explores its application in the process of coiling into the Bench Loong, paying special attention to the critical collision problem in the process, which ensures the reliability and expandability of the model. Furthermore, there is a paucity of extant research on the collision problem during the looping process of the Bench Loong, which is subjected to detailed analysis in this paper. The paper also proposes collision analysis criteria as a basic criterion for judging whether mutual collision occurs during the looping process [4]. The model enables the precise simulation of the looping process in the Bench Loong, allowing for the accurate prediction of its termination time. This provides novel insights and tools for the contemporary management and optimization of traditional folk activities.

A series of research processes and results of the "Bench Loong" model from the beginning of the orbit along the isometric solenoid to the termination moment of collision are shown. This paper firstly introduces the basic theories used in the modeling process, providing theoretical support for the study. Subsequently, the specific process of modeling and the core design ideas are explained in detail. Finally, by simulating the trajectory of the "Bench Dragon", the termination time and final state of its coiled-in are successfully predicted.

2. Relevant theories

2.1. Isometric Solenoid Equation

The expression for the isometric solenoid in the polar coordinate system is given by the following equation [5-6].

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

In the above equation *a* is a constant and *b* is a coefficient on the angle.

2.2. Equations of Motion

The Bench Loong model studied in this paper is a simulated Bench Loong structure formed by connecting the first long bench with the following 223 short benches. The long bench, with a board length of 341cm, serves as the head of the loong, while the other short benches, all with a board length of 220cm, serve as the rest of the body and tail of the loong. The process of traveling must use the loong's head as the starting point of movement to drive the movement of the Loong's body and ultimately form a model of isometric spiral traveling.

Select the coordinate origin *O* in the equidistant solenoid model as the reference point and set the value of the constant *a* in the solenoid equation to zero, so that the corresponding solenoid equation is written as follows:

$$r = b\theta = \frac{d_1\theta}{2\pi} \tag{2}$$

Where d_1 is the pitch of the isometric solenoid.

The linear velocity at the starting point of the front handle of the loong's head is 1 m/s and its value is kept constant, thus establishing the correspondence between the length of the spiral arc *s* and the pole angle θ_0 of the loong's front handle:

$$s = v_0 t = \int_{\theta_0}^{32\pi} \sqrt{r_0^2 + (\frac{\mathrm{d}r_0}{\mathrm{d}\theta})^2}\,\mathrm{d}\theta \tag{3}$$

A further simplification of the above equation gives an expression for the relationship between the handle pole angle θ_0 and the disk-in time *t* in front of the loong as[7-8]:

$$t = \frac{d_1}{2\pi}[\zeta\sqrt{4\zeta^2+1} + \frac{1}{2}\ln(2\zeta + \sqrt{4\zeta^2+1}) - \frac{\theta_0}{2}\sqrt{\theta_0^2+1} - \frac{1}{2}\ln(\theta_0 + \sqrt{\theta_0^2+1})] \tag{4}$$

In the above equation, the value of ζ is 16π.

Express the correspondence between the front handlebar angle θ_1 of the bench in Section 1 and the front handlebar θ_0 of the Loong using the following equation:

$$\frac{L_0}{\sin(\theta_1-\theta_0)}=\frac{b\theta_1}{\sin\theta'}=\frac{b\theta_1}{\sqrt{1-\cos^2\theta'}}=\frac{b\theta_1}{\sqrt{1-[\frac{(b\theta_1)^2-(b\theta_0)^2-L_0^2}{2b\theta_0L_0}]^2}} \tag{5}$$

Subsequently, after using the manual point A_1 as the starting point of the secondary study in front of the bench in section 1, and the manual point A_2 as the concurrent point in front of the bench in section 2, it is also possible to obtain the angular value of the pole angle of the handle in front of the bench in section 2 at different moments, and in this way obtain the recursive relationship with the expression as follows:

$$\frac{L_i}{\sin(\theta_{i+1}-\theta_i)}=\frac{b\theta_{i+1}}{\sin\theta_i'}=\frac{b\theta_{i+1}}{\sqrt{1-\cos^2\theta_i'}}=\frac{b\theta_{i+1}}{\sqrt{1-[\frac{(b\theta_{i+1})^2-(b\theta_i)^2-L_i^2}{2b\theta_iL_i}]^2}} \tag{6}$$

The length of L_0 is 286cm and the rest of the lengths L_i are 165cm.

Linear velocity of movement for any handle center at any moment in time, the expression is shown below [9-10]:

$$v_i(t)=\frac{\int_{\theta_{it}}^{\theta_{it}'}\sqrt{r_i^2+(\frac{\mathrm{d}r_i}{\mathrm{d}\theta})^2}\,\mathrm{d}\theta}{\Delta t}=\frac{\int_{\theta_{it}}^{\theta_{it}'}\sqrt{(\frac{d_1\theta_{it}}{2\pi})^2+\frac{d_1^2}{4\pi^2}(\frac{\mathrm{d}\theta_{it}}{\mathrm{d}\theta})^2}\,\mathrm{d}\theta}{\Delta t} \tag{7}$$

Based on the displacement and velocity information of the Bench Loong model during the solenoidal traveling process, the termination moment of the collision between the benches, as well as the positional coordinates of the handles and the running speed at the termination moment can be calculated.

3. Experiment

First of all, this paper presents two basic collision scenarios in which the loong's head collides with the loong's body:

(1) Collision scenario I

As the loong gradually cuts in, it will be in a position where the pitch of the handles on either side of the faucet bench is greater than the remaining pitch length. The situation can be interpreted as a stuck condition of the faucet bench due to the deepening of the loong and the gradual reduction of the pole diameter of the inner rim. The corresponding view of collision scenario I is shown in Figure 1 below.

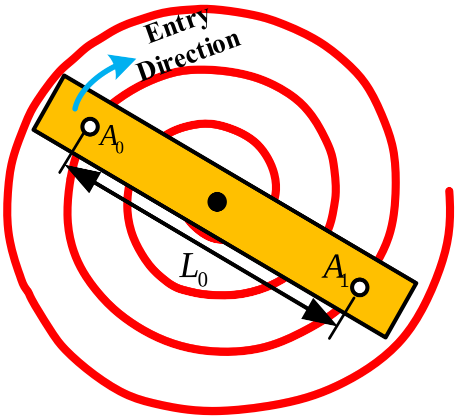

Figure 1. Collision scenario I top view

The polar angle of the loong at this point is denoted as θ_0. The sum of the radial distance $r(\theta_0)$ from the origin of the solenoid to the corresponding point A_0 of the moving point at this moment, and the radial distance $r(\theta_0+\pi)$ from the origin to the intersection of its inverse prolongation and the solenoid, should always be not less than the spacing between the handles of the two ends of the loong bench, L_0, which can be expressed by the following formula and used as an expression for the collision situation I:

$$r(\theta_0)+r(\theta_0+\pi)\geq L_0=286\text{cm}=2.86\text{m} \tag{8}$$

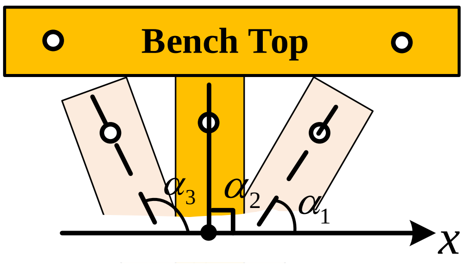

Figure 2. Top view of a multi-angle collision

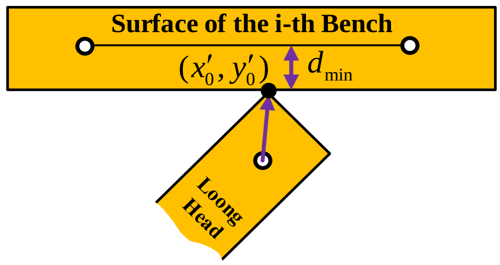

Figure 3. Critical states for collision scenario II

(2) Collision scenario II

The front part of the loong bench collides with one of the body benches at some point in time.

Critical conditions for collision form II need to be obtained in order to obtain constraints for type II collisions. Figures 2 and 3 below show a representation of the multi-angle collision case and the collision critical state for the second collision, respectively.

In order to obtain the coordinates of the boundary point of the collision between the loong's head and the loong body in Fig. 3, it is necessary to establish the angular relationship between the angle between the centerline of the loong's head and the horizontal direction, α, and the angle between the line connecting the front handle of the loong's head and the boundary point and the horizontal angle, γ, which is shown in Fig. 4 below.

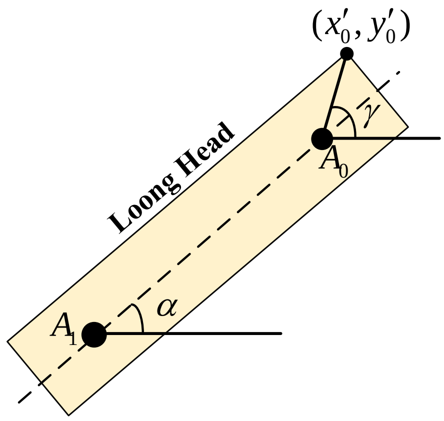

Figure 4. Loong handle centerline angle relationship established

Using the angle information in the figure, a tabular equation can be established for the relationship between the horizontal angle α and the horizontal angle γ:

$$\begin{cases}\alpha = \arctan\dfrac{y_1 - y_0}{x_1 - x_0}, x_0 > x_1 \\ \alpha = \arctan\dfrac{y_1 - y_0}{x_1 - x_0} - \pi, x_0 < x_1, y_0 < y_1 \\ \alpha = \arctan\dfrac{y_1 - y_0}{x_1 - x_0} + \pi, x_0 < x_1, y_0 > y_1\end{cases} \tag{9}$$

The difference between angle α and angle γ is defined as angle β, which is calculated as 28.61°. Accordingly, the expression for the relationship between γ and α can be obtained as:

$$\gamma = \alpha + \frac{\beta\pi}{180°} \tag{10}$$

From the above derivation, the relationship between the critical coordinate point and the coordinates $\left(x_0, y_0\right)$ of the handle in front of the loong can be obtained as:

$$\begin{cases}x_0' = x_0 + \sqrt{(L')^2 + d_{\min}^2}\cos\gamma \\ y_0' = y_0 + \sqrt{(L')^2 + d_{\min}^2}\sin\gamma\end{cases} \tag{11}$$

The second type of collision expression can then be obtained by specifying the slope-intercept equation for the centreline of the loong bench and determining the parameter values. The basic form of the slope-intercept equation is given based on the Cartesian coordinate system as:

$$y = kx + b_1 \tag{12}$$

Substituting the values of the right-angle coordinates of the handles in front of the bench in each section into the above equation respectively, the two parameter values are obtained as: $b_1 = y_{i+1} - kx_{i+1}$, $k = (y_{i+1} - y_i)/(x_{i+1} - x_i)$. Using the parameter values, the following type II collision expression is obtained as:

$$D_i = \frac{\left|kx_0' - y_0' + b_1\right|}{\sqrt{1+k^2}} \geq d_{\min} = 0.15\text{m} \tag{13}$$

Finally, the two collision expressions given above are combined and a total collision equation is obtained. This is called the collision analysis criterion.

$$\begin{cases}r(\theta_0) + r(\theta_0 + \pi) \geq L_0 = 286\text{cm} = 2.86\text{m} \\ D_i = \dfrac{\left|kx_0' - y_0' + b\right|}{\sqrt{1+k^2}} \geq d_{\min} = 0.15\text{m}\end{cases} \tag{14}$$

To ensure that the Bench Loong model is able to follow the established solenoidal route, it must not satisfy two collision scenarios at the same time, i.e., it must satisfy the collision analysis criterion. This collision analysis criterion is used as an evaluation index for calculating the termination time of the Bench Loong's travel, and the position coordinates and instantaneous speeds of the handles at the moment of termination can be further calculated.

4. Results

The analysis shows that as the number of screw coils decreases, the front end of the faucet must collide with the outer body of the Bench Loong at some point to terminate the operation of the whole Bench Loong, which is consistent with the collision scenario II. Taking the polar angle A of the front handle of the loong's head as a reference, there is only one possibility of collision between the loong's head and the body of the loong on the spiral located in area B. In a simplification, the following collision scenario can be given as an illustration. The theoretically possible head and body part collision scenarios are illustrated in Figure 5 below.

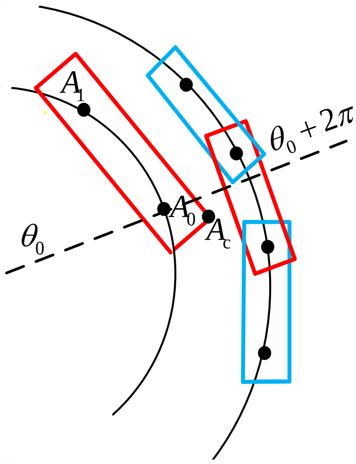

Figure 5. Illustration of possible collision scenarios

Through the triangular relationship between the two handles and the origin of the coordinates, the relationship expression between the polar angle θ_0 of the front handle of the loong's head and the polar angle θ_1 of the front handle of the first section of the loong's body is established and recursively obtained to obtain the expression of the recursive relationship, which is shown in Fig. 6 below.

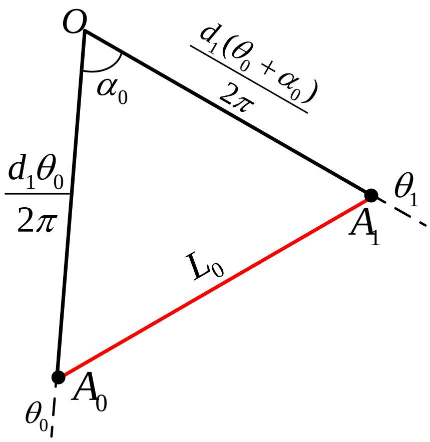

Figure 6. Representation of Trigonometric Relationships

Figure two rays OA_0 and OA_1 corresponding to the polar angle is the loong’s head before the handle polar angle θ_0 and the first section of the loong’s body before the handle of the polar angle θ_1, according to the cosine theorem for the angle α_0 to express there:

$$\alpha_0 = \arccos \frac{\frac{d_1^2\theta_0^2}{4\pi^2} + \frac{d_1^2(\theta_0+\alpha_0)^2}{4\pi^2} - L_0^2}{\frac{d_1^2\theta_0\cdot(\theta_0+\alpha_0)}{2\pi^2}} \tag{15}$$

The corresponding equation between the polar angles obtained from this is:

$$\theta_1 = \theta_0 + \alpha_0 = \theta_0 + \arccos \frac{d_1^2(\theta_0+\alpha_0)^2 + d_1^2\theta_0^2 - 4\pi^2 L_0^2}{2d_1^2\theta_0\cdot(\theta_0+\alpha_0)} \tag{16}$$

According to (16) the iterative formula can be obtained:

$$v_i = \frac{\int \sqrt{(\frac{d_1\theta_i}{2\pi})^2 + \frac{d_1^2}{4\pi^2}(\frac{d\theta_i}{d\theta})^2} d\theta}{\Delta t} \tag{17}$$

After a large amount of data fitting and experimental results analysis can be obtained "Bench Loong" traveling termination time of $t_m = 412.4753\text{s}$. The calculated partial handle positions and instantaneous velocities are summarized in Table 1 below. Through the calculation of the termination moment of the collision and the relationship between the position and instantaneous speed of each handle node corresponding to the termination moment, the relevant personnel can easily adjust the running trajectory and time of the Bench Loong, and give a timely turnaround program to avoid the collision of the overall structure.

Table 1. Position and velocity of the partial handle at the moment of termination

placement \ coordinate	x(m)	y(m)	velocity(m/s)
Loong's Head	1.211142	1.941963	0.999984
Body 1	-1.642698	1.754351	0.991521
Body 51	1.282560	4.326157	0.976840
Body 101	-0.537670	-5.879987	0.974470
Body 151	0.967429	-6.957658	0.973741
Body 201	-7.893364	-1.229363	0.973315
Loong's Tail	0.957625	8.322559	0.973121

The Figure .7 also shows the distribution of the positions of the handles of the Bench Loong model in relation to the termination moment when the head-body collision occurs.

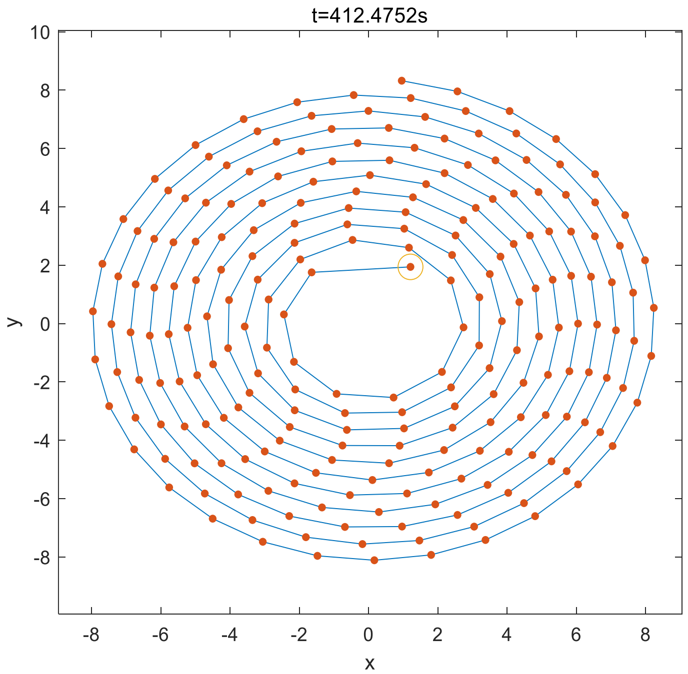

Figure 7. State of travel at the moment of collision

5. Conclusion

In this paper, a systematic dynamics analysis is carried out to analyze the collision problem between benches in Bench Loong, a traditional folklore activity. In this paper, the polar angles and velocities at each moment are introduced by transforming the equation relating the arc length to the polar angle recursively using the microelement method. The two main collision scenarios were then examined in detail, and basic criteria were obtained for determining whether mutual collisions would occur during the disk-in process. The results show that at the moment of termination, the coordinate positions and velocities of the loong's head, the segments of the loong's body, and the loong's tail are in accordance with the expectations, which verifies the reliability of our model. These results not only provide detailed data support for the simulation of the Bench Loong's movement process, but also enhance the spectacle and reliability of the Bench Loong's circling process.

In the course of future research, the model can also be applied to the analysis and simulation of the solenoidal equations, the analysis of the kinematics of solenoidal magnetic fields, and the recursion of the relationship between the states of motion of multiple objects, among many other fields.

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