Establishment of Dynamic Collision Detection Model Based on Vector Method

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Abstract. The 'bench dragon' is a traditional local folk cultural activity in the Zhejiang Fujian region. The purpose of this article is to determine the time when the dragon dance team cannot continue to reel in along a specific spiral, and to solve for the position and speed of the dragon dance team at this time. At present, no scholars have conducted reliable research on this. We first need to establish a kinematic equation based on the spiral parameter equation to calculate the position coordinates of each handle at each moment. Then, we need to establish a dynamic collision detection model based on vector method and determine the collision conditions. Using this model, we can determine the specific time of collision and obtain the position coordinates and velocity of each handle of the dragon dance team at this time. The final calculation shows that the dragon head collided approximately at the fourth circle from the inside out, with a collision time of 413 seconds. This model effectively solves this problem and fills the gap in related research.

Keywords: Spiral parameter equation, Binary method, Vector method, Model simplification, Collision detection.

1. Introduction

The 'bench dragon' is a traditional local folk cultural activity in the Zhejiang Fujian region. When coiling a dragon, people connect dozens to hundreds of benches end-to-end, forming a winding and twisting dragon bench. The dragon head leads the way, and the dragon body and tail spiral together, forming a circular disk shape. When the dragon bench spirals in along the spiral path, it will be unable to continue coiling due to collision. In order to apply it more reasonably, the academic community often cares about the collision problem of connected geometry. To address the collision detection problem, J.J. Sylvester proposed the bounding box detection method to solve the minimum bounding circle (sphere) problem[1]; Hermann Minkowski proposed the Separation Axis Theorem (OBB) method, which is mainly used to solve the collision problem of convex polygons[2]; Lin and Canny proposed the Lin Canny detection method, which is commonly used in fields such as graphics and physics engines to solve the algorithm for finding the nearest point pair between two convex hull geometries[3]; Georgy Fedoseevich Voronoi proposed a spatial segmentation method to optimize collision detection algorithms and improve computational efficiency[4]. Their work provides a theoretical basis for the establishment of collision detection models. However, these methods generally have disadvantages such as high computational complexity and low detection accuracy. In order to solve these problems, this article simplifies the model to reduce computational complexity, while using vector method to improve computational accuracy. Innovatively, a dynamic collision detection model is established, which is applied to such problems for the first time and solves the problem well. In order to better describe the model proposed in this article, it is divided into five chapters for discussion: the first part is the introduction, which introduces the problem background, research status, research questions, contribution points of this article, and structural description of the article; The second part is the relevant theory, which introduces the basic knowledge of the algorithms and models involved in this article; The third part is the experiment, which introduces the experimental ideas, experimental design, experimental process, and experimental conclusions; The third part is the conclusion, which introduces the results and analysis of the problem; The fifth part is a summary, which summarizes the content of the article and proposes a model outlook.

2. Correlation theory

(1) Archimedes spiral: The polar coordinate equation of Archimedes spiral is $\boldsymbol{r = a + b\theta}$, where a and b are both real numbers. Changing parameter a is equivalent to rotating a spiral line, while parameter b controls the distance between adjacent curves.

(2) Simplification of dynamic collision detection model: The collision detection model is a model established to determine whether two bodies are in contact. In this article, through problem analysis, the issue of whether there will be collisions between the benches in each section is simplified as the question of whether the dragon head and the first section of the dragon body will collide with other benches.

(3) Vector method: an important method in analytic geometry that can transform geometric problems into numerical calculations, simplify complexity, and have unique advantages in solving algebraic, geometric, and other problems. In this article, the unit vector representing the direction is obtained through position coordinates to assist in solving.

3. Experiment

This problem requires solving the termination time of the dragon dance team's disk insertion, so that there is no collision between the benches, and solving the motion state of the dragon dance team. We need to establish a dynamic collision detection model to solve the time of the first collision. In the modeling process, we need to consider various possibilities of edge and corner collisions of the stool, as well as multiple possibilities of collisions between connected and unconnected stools. We need to establish a suitable detection mechanism, and at the same time, solving the position of each handle requires a large amount of computation, so we need to pay attention to selecting the appropriate method.

Based on the above analysis, this article constructs a dynamic collision detection model based on vector method. The specific operation is as follows:

Firstly, establish the spiral parameter equation. Based on this, the movement status of each handle can be determined:

$$r = r_0 - \frac{p}{2\pi}\theta \tag{1}$$

Among them, the value of r_0 is 8.8m, and the value of p is 0.55m.

Next, establish a dynamic collision detection model[5]. To reduce redundant calculations and improve computational efficiency, this article first simplifies the problem:

Given the known conditions, the length of the stools is the same except for the faucet, and the connected stools will not collide. Therefore, the motion trajectory of each section of the dragon body and tail is the same as that of the first section of the dragon body, so it is only necessary to consider whether the dragon head and the first section of the dragon body will collide with other benches.

Let the line connecting the two points on the outside of the dragon head be l_1, and the line connecting the two points on the outside of the first dragon body be l_2. Therefore, if the first collision occurs, it will only occur between a point on the line l_1 or l_2 and the adjacent outer ring bench. Thus, as shown in Figure 1, the model simplification is completed.

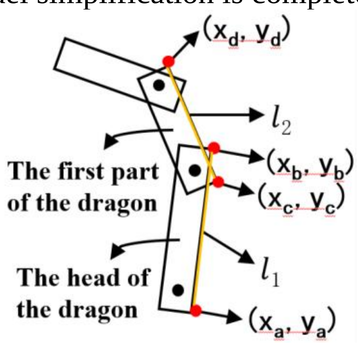

Figure 1. Schematic diagram of simplified model

Consider the collision detection conditions for the faucet: let the horizontal axis of the collision point be x_p, and the horizontal coordinates of the two points on the outside of the faucet be x_a, x_b. Due to the uncertainty of the size relationship between x_a and x_b, it is necessary to discuss them in two cases: $x_a \leq x_b$ and $x_b \leq x_a$. From this, collision detection conditions can be obtained: $x_a \leq x_p \leq x_b$ or $x_b \leq x_p \leq x_a$. For the first section of the dragon body, collision detection conditions similar to a dragon head can be obtained.

The schematic diagram of collision between the dragon head or the first dragon body and the adjacent outer ring bench is shown in Figure 2:

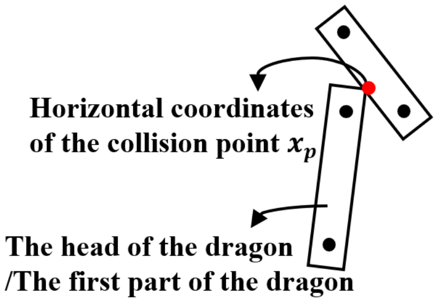

Figure 2. Schematic diagram of collision points

In order to perform collision condition detection, it is necessary to solve for the coordinates of the two outer points of the dragon head or the first dragon body, as well as the coordinates of the two inner points of the remaining dragon bodies. This article takes the solution of the outer point (x_a, y_a) of the dragon head as an example to demonstrate the process of using vector method to obtain the above coordinates[6], as shown in Figure 3.

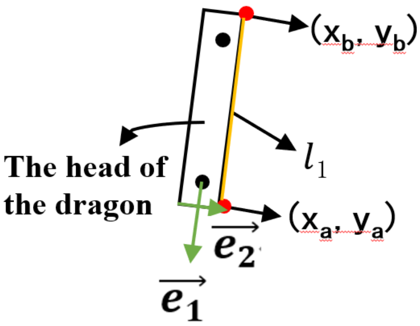

Figure 3. Vector Diagram

Let $\overrightarrow{e_1}$ be the unit vector obtained by rotating the finger in front of the dragon towards the direction of the dragon head, and $\overrightarrow{e_2}$ be the unit vector obtained by rotating $\overrightarrow{e_1}$ counterclockwise by 90 degrees[6]. The expressions for $\overrightarrow{e_1}$ and $\overrightarrow{e_2}$ can be calculated as follows:

$$\begin{cases} \overrightarrow{e_1} = \left(\frac{x_0 - x_1}{\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}}, \frac{y_0 - y_1}{\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}}\right) \\ \overrightarrow{e_2} = \left(-\frac{y_0 - y_1}{\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}}, \frac{x_0 - x_1}{\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}}\right) \end{cases} \tag{2}$$

Let d_1 be the distance from the handle to the shorter side of the stool, and d_2 be half the width and length of the board. Substituting $\overrightarrow{e_1}, \overrightarrow{e_2}$ into the expression $(x_a, y_a) = (x_1, y_1) + d_1\overrightarrow{e_1} + d_2\overrightarrow{e_2}$, we can obtain (x_a, y_a), and similarly, we can calculate the coordinates of other points.[7]

To perform collision detection, it is also necessary to obtain the abscissa of the collision point. Taking the collision between the dragon head and the adjacent outer ring bench as an example, the equation of line l_1 can be obtained by calculating (x_a, y_a) and (x_b, y_b), and the equation of line l_p can be obtained by solving them together[8]. The collision point is the intersection point of the two lines, and x_p can be obtained by combining them, as shown in Figure 4. The collision of the dragon body in the first section is the same.

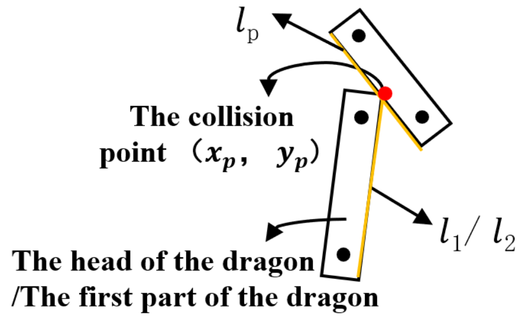

Figure 4. Schematic diagram of the intersection point of two straight lines

At this point, the collision detection model has been established.

Next, let's take a look at the specific solution process:

First, solve for $\overrightarrow{e_1}$ and $\overrightarrow{e_2}$. Firstly, initialize the parameters. In the equation, x_0, y_0, x_1 and y_1 are the horizontal and vertical coordinates of the front handle of the dragon head and the front handle of the first section of the dragon body, respectively. Their solutions have been solved in problem one. By substituting them into the formula and solving it in Matlab, $\overrightarrow{e_1}$ and $\overrightarrow{e_2}$ can be obtained[9]. The rest is the same.

After finding $\overrightarrow{e_1}$ and $\overrightarrow{\boldsymbol{e_2}}$, substitute them into $(x_a, y_a) = (x_1, y_1) + d_1\overrightarrow{e_1} + d_2\overrightarrow{e_2}$, where d_1 is 0.275m and d_2 is 0.15m, to obtain x_a. Similarly, x_b, x_c and x_d can be obtained.

Taking the collision of the dragon head as an example, first solve l_1 using the two-point equation of the straight line:

$$\frac{y-y_b}{y_a-y_b} = \frac{x-x_b}{x_a-x_b} \tag{3}$$

By following the same principle, we can obtain l_p. By combining two straight lines, let $l_1 = l_p$ to obtain x_p. The collision of the dragon body in the first section is the same.

Based on the above solution, collision detection can be performed for $(x_a, y_a), (x_b, y_b), (x_c, y_c), (x_d, y_d)$ are used for detection[10]. When any point meets the collision detection conditions, it is considered to have collided. The position of the point where the collision occurred can be determined. From problem one, the corresponding relationship between different points and positions at different times can be obtained, and the time of collision can be determined, which is the termination time of the dragon dance team's entry as mentioned in problem two.

The final calculated time is 413 seconds.

By substituting the termination time into the code written in Matlab, the position and speed of each handle of the dragon dance team at this time can be obtained.

4. Experimental conclusion

After establishing and solving the model as described above, the position and velocity of the dragon head and each section of the dragon body can be obtained, some of which are shown in the table below, and the results are visualized.

The specific results are shown in Table 1:

Table 1. Results of Position and Velocity

	x(m)	y(m)	velocity(m/s)
Faucet	1.607860	1.600338	0.999256
Section 1 Dragon Body	-1.216456	2.050716	0.990521
Chapter 51: Dragon Body	1.761036	4.143629	0.976002
Section 101: Dragon Body	-1.042989	-5.803967	0.973757
Chapter 151: Dragon Body	0.458904	-7.003208	0.972843
Section 201: Dragon Body	-7.950194	-0.722213	0.972347
Dragon Tail (Rear)	1.461716	8.243548	0.972193

The simulated trajectories of each dragon body are shown in Figure 5:

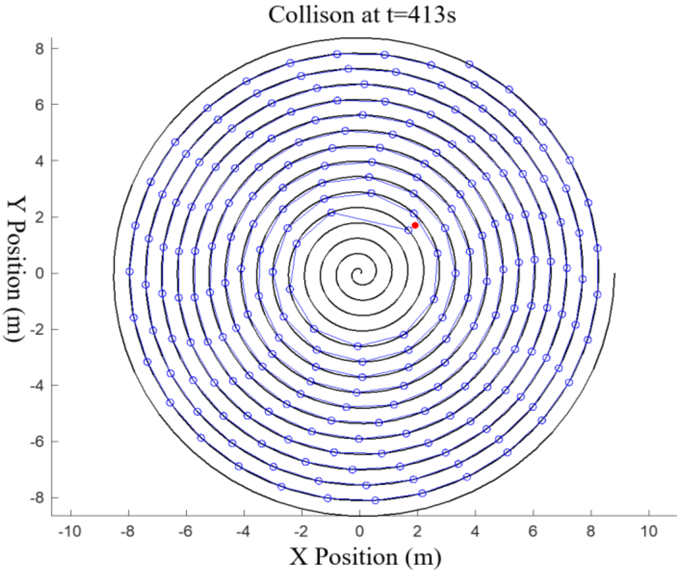

Figure 5 Simulation diagram of dragon body trajectories for each section

The collision time can be calculated as 413 seconds, and from the trajectory simulation diagram, it can be seen that the dragon head collided approximately at the fourth circle from the inside out, and the collision time is consistent with the calculated result.

5. Conclusion

In this paper, we established a dynamic collision detection model for the collision problem of dragon dance and solved it. We obtained the time when the dragon dance team could no longer continue to reel in, as well as the position and velocity of each handle when a collision occurred. Based on this research, we can further determine the minimum pitch, shortest turning path, and maximum travel speed of the spiral line under given constraints. This can effectively improve the viewing experience of the dragon dance team when they can freely reel in and out. This article also verified the reliability of the model through trajectory simulation diagrams and other methods. The model proposed in this article can be used to improve the viewing experience of dragon dance and perform collision detection on other models. Through the above research, this article has solved previously unexplored related problems, providing a reliable basis for future academic research on related issues.

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