International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 6470-6479

https://doi.org/10.70517/ijhsa464549

The kinematic characteristics and collision analysis of dragon dance team based on Archimedean spiral

Kaijia Luo[1,*], Jiayang Xiao[2] and Junnan Zhong[3]
[1] School of Computer Science and Technology, Guangdong University of Technology, Guangzhou, Guangdong, 510006, China
[2] School of Chemical Engineering and Light Industry, Guangdong University of Technology, Guangzhou, Guangdong, 510006, China
[3] College of Electronics and Information Engineering, Shenzhen University, Shenzhen, Guangdong, 518060, China
Corresponding authors: (e-mail: 13172598138@163.com).

Abstract Dragon dance, a traditional folk activity, demands enhanced safety and performance. Yet, research on its kinematic models and collision analysis remains scarce. This study aims to fill this gap. Employing plane geometry, physical kinematics, and mathematical proof, it constructs kinematic models for the dragon head, body, and tail based on the Archimedean spiral and recursive methods, while defining "safe distance" for collision analysis. Simulation shows the team halts due to collision at t=416 seconds, revealing the dragon body's speed decline with distance from the head and the head's initial speed impact on collision time. The innovation lies in integrating geometric and physical methods to precisely model dragon dance movements, offering a scientific safety - management foundation and a novel approach for other complex systems' kinematic studies.

Index Terms Dragon Dance Team Kinematics, Geometric Approximation Analysis, Safety Distance, Collision Termination Model

I. Introduction

In recent years, with the continuous promotion of the protection and inheritance of intangible cultural heritage, the safety and performance quality of dragon dance, a traditional folk activity, have received widespread attention. How to ensure that there are no collisions between members of the dragon dance team has become an urgent problem to be solved in dragon dance activities. In existing research, Chen Yang et al. (2024) proposed a method of calibrating the absolute positioning accuracy of industrial robots through kinematic models, effectively improving the positioning accuracy of robots [1]. Li Yihui et al. (2024) proposed a geometric inverse kinematics method for the inverse kinematics problem of nodal kinematic models, providing a new solution for precise control of complex mechanical systems [2]. Zhou Jia (2023) explored collision theory models in physics, although his research involved collision theory, it did not directly apply this theory to dragon dance team systems with specific cultural backgrounds and dynamic characteristics [3]. In addition, Yao et al. (2021) focused on the study of particle collision behavior in high concentration particle suspensions. Although some progress has been made in the field of particle dynamics, there is still limited research on the kinematic models and potential collision analysis of complex systems composed of multiple connected units, such as the Dragon Dance Team [4]. This article provides an in-depth analysis of the kinematic characteristics and potential collision problems of dragon dance teams, and innovatively defines the safety distance and establishes a collision termination model, providing a scientific basis for the safety management of dragon dance performances.

The main contributions of this paper include: 1) A comprehensive kinematic model based on plane geometry and physical kinematics was proposed for the first time to address the kinematic characteristics and potential collision problems of dragon dance teams; 2) Innovatively defined the safe distance in dragon dance team movements and established a collision termination model; 3) The simulation experiment was conducted using MATLAB software, and the collision equation was solved numerically to verify the rationality and practicality of the established model.

The structure of this paper is as follows: the first part is the introduction, which introduces the background, research status, and research contribution of the intangible cultural heritage of dragon dance; The second part is the methodology, which elaborates on the research methods adopted in this article, including the plane geometry method for establishing the kinematic model of the dragon dance team and physical kinematic analysis; The third part is experimental design and analysis, which describes the specific design, implementation process, and data analysis methods of the experiment; The fourth part is the results, summarizing the main findings of the experimental study, including collision analysis of dragon dance teams under specific conditions; The fifth part is the conclusion, which summarizes the main achievements of this study, explores its significance for the safety management of dragon dance performances, and proposes future research directions.

II. Related Theories

For the front handle of the dragon head at time t, when it is wound clockwise along an equidistant spiral with a pitch of 55 cm, the trajectory equation in polar coordinates obtained based on the standard Archimedean spiral is [5]:

$$r_{t0} = \frac{b}{2\pi}\theta_{t0} \tag{1}$$

Among them, $b = 0.55m$ is the pitch of the equidistant spiral. At the initial moment, the dragon head is located at the 16th turn of the spiral, so $\theta_{t0} = 16\times 2\pi = 32\pi$. θ_{t0} represents the polar angle of the initial position, and r_{t0} represents the radius of the spiral. According to the trajectory equation in polar coordinate system, the coordinate equation in Cartesian coordinate system is:

$$\begin{cases} x = r\cos\theta = \left(\dfrac{b}{2\pi}\theta\right)\cos\theta \\ y = \sin\theta = \left(\dfrac{b}{2\pi}\theta\right)\sin\theta \end{cases} \tag{2}$$

The standard Archimedean spiral defines angular velocity as constant, while linear velocity is variable [6]. This obviously does not apply here. Redefine as the constant line velocity v of the dragon head, while the variable angular velocity w [7].

The model assumes that the travel speed of the front handle of the dragon head, $v = 1m/s$, remains constant, and the distance ds it moves during time dt can be approximated as the arc length between adjacent position points. Define point H_{t0} as the position point of the front handle of the dragon head at the t-th second, and $d\theta_{t0}$ as the angle at which the front handle of the dragon head passes along the spiral during time dt. By geometric approximation, the small amount of movement is magnified, and the spiral arc length of the front handle of the dragon head moving from one point to the next is approximated as a circular arc from point H_{t0} to point $H_{(t+dt)0}$, as shown in Figure 1.

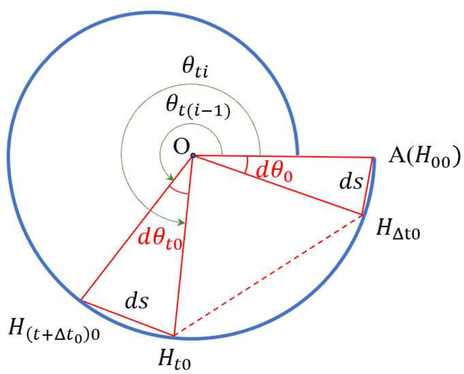

Figure 1: Schematic diagram of the position of the front handle of the faucet at different times

Due to the clockwise rotation of the front handle of the dragon head along the spiral, the angle θ increases with time [8].

Convert the polar coordinate position to the Cartesian coordinate position to obtain the update formula for the position of the front handle of the dragon head in the Cartesian coordinate system [9]:

$$\begin{cases} x_{(t+dt)0} = \left[\dfrac{b}{2\pi}\theta(t+dt)\right]\cdot\cos\left(\theta_{t0} - d\theta_{t0}\right) \\ y_{(t+dt)0} = \left[\dfrac{b}{2\pi}\theta(t+dt)\right]\cdot\sin\left(\theta_{t0} - d\theta_{t0}\right) \end{cases} \tag{3}$$

Afterwards, the kinematic model of the dragon head is used to determine the position coordinates of the front handle of the dragon body at any time. For the t-th second, the position of the front handle of the dragon head is determined by its polar coordinates (r_{t0}, θ_{t0}), while the position of the front handle of the i-th dragon body is represented by $\left(r_{t(i+1)}, \theta_{t(i+1)}\right)$. The key to the model lies in determining the position coordinates of the front handles of the dragon body and tail segments through geometric relationships and recursive methods. Specifically, the position of the first section of the dragon body front handle is first deduced based on the position of the dragon head front handle and the known length of the stool. For the recursion from the dragon head to the first section of the dragon body, the length of the stool is approximated as the arc length, that is, $l_1 = 2.86m \approx r_{t0} \cdot d\theta_{t0}$. Next, for the recursion of each segment inside the dragon body, we use the arc length corresponding to the polar angle difference between adjacent benches to approximate the actual length of the bench [10]. For the recursion from the $(i-1)$-th dragon body to the i-th dragon body, the length of the stool is also approximated as the arc length, that is, $l_2 = 1.65m \approx r_{t(i-1)} \cdot d\theta_{t(i-1)}$, as shown in Figure 2.

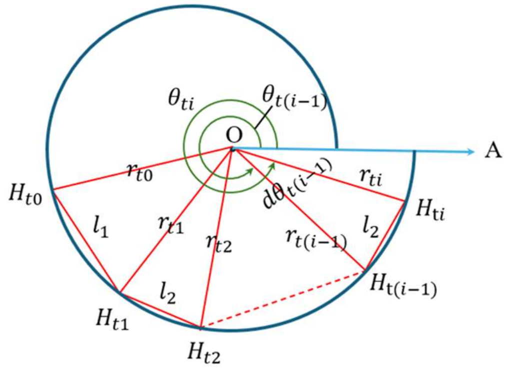

Figure 2: Schematic diagram of the positions of each segment of the dragon body and the dragon tail at the second t

In this way, a recursive formula for the position of the front handle of each segment of the dragon body and tail can be obtained, so as to traverse all time points and obtain the position coordinates of the i-th segment of the dragon body front handle at any time [11].

$$\text{Section 1 Dragon Body}\begin{cases}\theta_{t1} = \theta_{t0} + d\theta_{t0} \\ r_{t1} = \dfrac{b}{2\pi}\theta_{t1}\end{cases} \tag{4}$$

$$\text{Section i: Dragon Body and Dragon Tail}\begin{cases}\theta_{ti} = \theta_{t(i-1)} + d\theta_{t(i-1)} \\ r_{ti} = \dfrac{b}{2\pi}\theta_{ti}\end{cases} \tag{5}$$

Assuming the initial velocity of the entire dragon team is 1m/s, according to equations (4) and (5), the position equations of the i-th dragon body front handle at the t-th and $(t+dt)$-th seconds can be obtained, namely the position coordinates (r_{ti}, θ_{ti}) and $(r_{(i+1)i}, \theta_{(i+1)i})$ of points H_{ti} and $H_{(t+1)i}$, as shown in Figure 3.

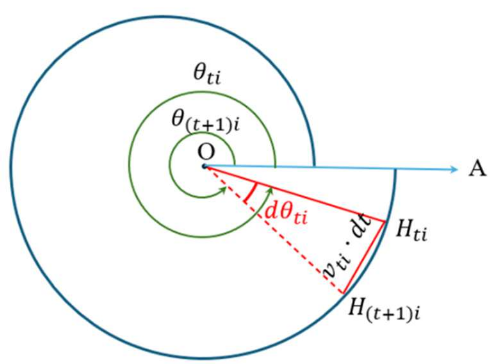

Figure 3: Schematic diagram of the position of the i-th dragon body from the t-th second to the $t+dt$ second

Let v_{ti} represent the velocity of the i-th dragon body front handle at time t. Using differential thinking, the distance traveled by the i-th dragon body front handle within dt seconds can be approximated as a straight line $H_{ti}H_{(t+1)i}$, and the velocity equation of the i-th dragon body front handle at time t can be obtained:

$$v_{ti} = \frac{r_{ti} \cdot d\theta_{ti}}{dt} \tag{6}$$

III. Experiments

III. A. Technology Roadmap

Firstly, to study the dragon dance team's kinematic model, the first step is to establish a coordinate system and redefine the Archimedean spiral. Taking the spiral center as the origin, both polar and Cartesian coordinate systems are constructed. This setup allows for easy description of the dragon head's motion. The conversion between the two systems simplifies data analysis and model building, laying a solid foundation for subsequent research. Based on this, a kinematic model of the dragon head is constructed, and the recursive formulas for the position and velocity of the dragon head are derived through geometric approximation and recursive thinking, obtaining the motion state of the dragon head at any time. Subsequently, building on the dragon head's kinematic model, kinematic models for the dragon body and tail are established. Using geometric relationships and recursive methods, the positions and velocities of their handle points are calculated. Finally, collision analysis is performed and a terminaodel is set up. By defining a safe distance and analyzing possible collision situations, plane geometry knowledge is applied to determine the termination time of the dragon dance team's disk insertion, thereby completing the construction and analysis of the entire "bench dragon" kinematic model.

When analyzing the possibility of collisions between benches during the movement of the bench dragon, it is first assumed that the motion from point A to point B is small, so the distance to the center of the spiral can be considered constant, that is, AO=BO, CO=DO. This assumption helps simplify the model, allowing us to more clearly understand the potential collision situations between the benches. When the chord lengths are the same, a smaller radius will result in a larger circumferential angle, i.e., $\theta_2 > \theta_1$. This means that the curvature is also greater. The greater the curvature, the higher the likelihood of collisions between benches during their movement. This is because, for the same angle change, a bench with greater curvature will cover a larger arc length, thus increasing the opportunity to intersect with other benches.

Figure 4 shows a schematic diagram of the Archimedes spiral motion model. In the diagram, two circles with different radii represent benches at different positions. The smaller radius r_2 corresponds to a larger circumferential angle θ_2, while the larger radius r_1 corresponds to a smaller circumferential angle θ_1. This relationship intuitively demonstrates the relationship between curvature and radius, as well as the impact of curvature on the likelihood of collisions between benches during their movement.

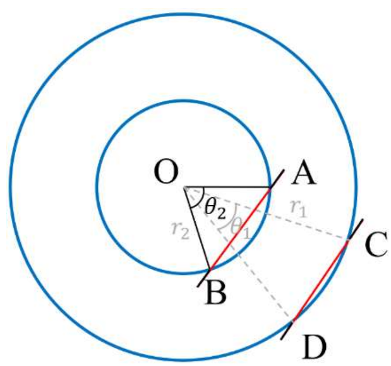

Figure 4: Schematic diagram of Archimedes spiral motion model

Subsequently, based on the dragon head's kinematic model, kinematic models for the dragon body and tail are established. Geometric relationships and recursive methods are used to calculate the positions and velocities of their handle points. Finally, a collision analysis is conducted, and a termination model is set up. By defining a safe distance and applying plane geometry knowledge to analyze possible collision situations, the termination time of the dragon dance team's disk insertion is determined, thus completing the construction and analysis of the entire "bench dragon" kinematic model [12]. In the kinematic analysis of the bench dragon, the geometric relationship between the structural dimensions of its components plays a pivotal role in determining collision risks. Specifically, the length of the "board head" is found to exceed half of the board width, a critical parameter that influences the spatial overlap probability between different segments. This dimensional characteristic is key to ruling out the possibility of initial contact between the "board body" segments. Mathematically, the longitudinal extension of the dragon head ensures that its leading edge extends beyond the lateral midline of any adjacent dragon body segment when aligned along the same radial or tangential path during movement. However, the symmetric arrangement and constrained motion of consecutive body segments—connected by handles and moving in coordinated spiral or circular trajectories—limit their lateral deviation, making direct body - to - body contact geometrically less likely unless extreme angular distortions occur. By contrast, the dragon head, acting as the maneuvering front end with greater length and located closer to the spiral center, creates a higher risk of intersecting with the dragon body's trajectory. This configuration means the head's trajectory is more likely to cut across the body's segments, especially when the team executes coiling or disk - insertion maneuvers that involve rapid radial and angular changes. The geometric exclusion of initial body - to - body contact, combined with the head's dimensional and positional characteristics, leads to the inference that the most probable collision type is between the dragon head and the dragon body, as visually illustrated in Figure 5.

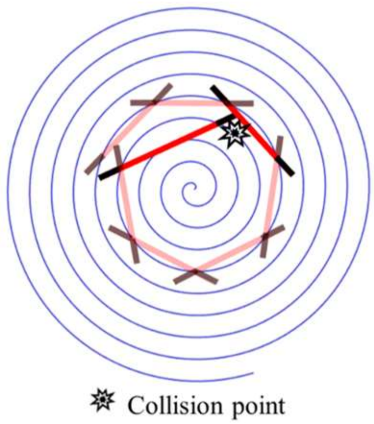

Figure 5: Schematic diagram of collision points between benches

This conclusion is further robustly supported by detailed kinematic simulations. These simulations meticulously track and analyze the movement patterns, revealing that the velocity vector of the head and its positional coordinates repeatedly and significantly enter the safety margin of adjacent body segments well in advance. This occurs long before any of the body segments come close to each other's critical distance, providing compelling evidence for the importance of closely monitoring head movements in safeguarding overall body integrity and preventing potential collisions.

Before defining the safe distance $l_{\max}$, it is assumed that h' 'represented by the yellow line on the diagram is approximately equal to the distance from the board head (the distance from the small hole of the front handle of the faucet to the board head) $h = 27.5cm$. The distance from the small hole on the front handle of the dragon head to the dragon body can be approximated as the distance d from a point to a straight line, as shown in Figure 6.

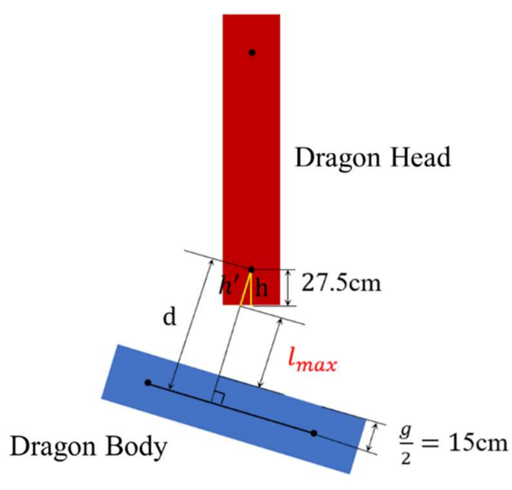

Figure 6: Schematic diagram of mutual collision between benches

The width of the dragon body cannot be ignored. Although it will not cause collisions between dragon bodies, it will result in a decrease in the safety distance $l_{\max}$. Therefore, the definition of $l_{\max}$ is:

$$l_{\max} = d - h' - \frac{g}{2} = d - h - \frac{g}{2} = (d - 42.5)cm \tag{7}$$

III. B. Establishment of Collision Equation

During the intricate coiling process of the bench dragon, when assuming that the centers of each handle are precisely positioned on the spiral, a series of geometric and kinematic phenomena unfold. It is evident that the head of the dragon, acting as the guiding element, will traverse the spiral in a direction towards the outer ring.

This movement is not only a visual spectacle but also a key determinant of the overall formation's dynamics. For the dragon body stools, their motion pattern is equally captivating. Each dragon body stool will pass through two handle points that are situated on the spiral, effectively cutting through the spiral coil at the location of the handle point.

As the handle point gradually approaches the origin of the spiral, an interesting transformation occurs. The range within which the dragon body stool cuts the spiral coil expands significantly, causing a greater disruption to the otherwise smooth spiral pattern.

Concurrently, the straight line formed by the alignment of the dragon body stools gradually converges towards the head of the dragon, creating a visually striking and geometrically complex interplay between the different components of the bench dragon. This dynamic relationship between the dragon head, dragon body stools, and the spiral trajectory is crucial for understanding the mechanics and aesthetics of the bench dragon's coiling process, and it also plays a pivotal role in analyzing potential collision risks and optimizing the performance's safety and visual appeal [13]. When close enough, the dragon head will collide with the dragon body.

According to the kinematic model of the dragon team, the Cartesian coordinates (x_{ti}, y_{ti}) of the front handle of the dragon head and the position coordinates of the i -th front handle of the dragon body can be updated as the disk insertion time increases. Each time we move forward, we can calculate the distance from the bench line closest to the front handle of the faucet to the front handle of the faucet, and compare it with the safe distance $l_{\max}$ to determine whether a collision has occurred at that moment. The specific steps are as follows:

Firstly, using the position coordinates in the Cartesian coordinate system, determine the bench line closest to the front handle of the dragon head, which is the front handle point of the dragon body closest to the front handle point of the dragon head. The line connecting adjacent points is the bench line. At the t second, the position coordinates of the front handle of the faucet are (r_{tk}, θ_{t0}). Let the dragon body front handle point closest to the dragon head front handle point be the position of the k dragon body front handle (r_{tk}, θ_{tk}), and the value of k satisfies:

$$k = i, \min\left\{\left|\theta_{ti} - \theta_{t0} - 2\pi\right|\right\} \tag{8}$$

Next, the kinematic model of the dragon team is used to obtain the position coordinates $\left(x_{t(k-1)}, y_{t(k-1)}\right), \left(x_{tk}, y_{tk}\right), \left(x_{t(k+1)}, y_{t(k+1)}\right)$ of the front handle points of the dragon body at the $k-1,\ k,\ and\ k+1$ stages. The linear equations of the bench line $H_{t(k-1)}H_{tk}$ and the line $H_t H_{t(k+1)}$ can be calculated using the following formula for two points, $H_i(x_i, y_i)$ and $H_j(x_j, y_j)$ [14]:

$$Ax + By + C = 0 \tag{9}$$

$$A = (y_j - y_i), B = -(x_j - x_i), C = x_j y_i - x_i, y_j \tag{10}$$

Substituting the position coordinates of the front handle points of the dragon body in sections $k-1,\ k,\ and\ k+1$ into equations (9) and (10) yields [15]:

$$\begin{cases} H_{t(k-1)}H_{tk}\text{:}\left(y_{tk} - y_{t(k-1)}\right)x - \left(x_{tk} - x_{t(k-1)}\right)y + \left[x_{tk}y_{t(k-1)} - x_{t(k-1)}y_{tk}\right] = 0 \\ H_{tk}H_{t(k+1)}\text{:}\left(y_{t(k+1)} - y_{tk}\right)x - \left(x_{t(k+1)} - x_{tk}\right)y + \left[x_{t(k+1)}y_{tk} - x_{tk}y_{t(k+1)}\right] = 0 \end{cases} \tag{11}$$

Then, according to the distance formula from point to line, calculate d_1 and d_2. The distance formula from point $H_0(x_{t0}, y_{t0})$ to line $H_i H_j$ is [16]:

$$d = \frac{Ax + By + C}{\sqrt{A^2 + B^2}} \tag{12}$$

Among them, $A,\ B,\ and\ C$ are the same as equation (10). The formula for the distance $H_0(x_{t0}, y_{t0})$ from point $H_{t(k-1)}H_{tk}$ to lines $H_{tk}H_{t(k-1)}$ is:

$$d = \frac{Ax_{t0} + By_{t0} + C}{\sqrt{A^2 + B^2}} \tag{13}$$

Among them, when $A = \left(y_{tk} - y_{t(k-1)}\right)$, $B = -\left(x_{tk} - x_{t(k-1)}\right)$, $C_1 = \left[x_{tk}y_{t(k-1)} - x_{t(k-1)}y_{tk}\right]$, the distance d_1 obtained is the distance d_1 between the front handle point H_{t0} of the faucet and the bench line $H_{t(k-1)}H_{tk}$. When $A_2 = \left(y_{t(k+1)} - y_{tk}\right), B_2 = -\left(x_{t(k+1)} - x_{tk}\right), C_1 = \left[x_{t(k+1)}y_{tk} - x_{tk}y_{t(k+1)}\right]$, the distance d_2 obtained is the distance d_2 between the front handle point H_{t0} of the faucet and the bench line $H_{tk}H_{t(k+1)}$ [17].

Afterwards, compare d_1, d_2, and $l_{\max}$ to determine if a collision occurred at the t second. If both d_1 and d_2 are less than $l_{\max}$, no collision will occur. Increase t to the $t+dt$ second and repeat the above steps until the following conditions are met [18]:

$$l_{\max} = d - 42.5 \le 0 \tag{14}$$

If equation (14) is satisfied, that is, d_1 or $d_2 \le 42.5cm$, at this time the dragon head deviates from the safe distance and collides with the dragon body, the obtained t is the termination time of the dragon dance team's entry.

Finally, leveraging the sophisticated kinematic model specifically developed for the dragon team, a comprehensive set of calculations is carried out. This model, which takes into account various factors such as the team members' coordinated movements, the dynamic interactions between different parts of the dragon, and the overall rhythm of the performance, precisely outputs the position and velocity of each member of the dragon dance team at the termination time. These detailed results provide valuable insights into the team's final state of motion and can be used for further analysis and improvement of their performance.

III. C. Experimental Environment and Model Solving

This experiment was executed within the Windows 11 operating system environment, utilizing a laptop outfitted with a 12th generation Intel Core i5 processor featuring a clock speed of 1.70GHz and 16GB of memory.

The MATLAB software employed in this study was the R2023a version, which could be launched via a desktop shortcut and was integrated with several toolkits, such as the Statistics and Machine Learning Toolbox, Control System Toolbox, and Computational Fluid Dynamics Toolbox, among others. These toolkits played a crucial role in facilitating the complex mathematical modeling and numerical simulations essential for this research.

The experimental process began by formulating MATLAB scripts to update the position coordinates of the dragon head and the front handle of the dragon body, drawing on the kinematic model of the dragon dance team. These scripts were crafted to accommodate the dynamic aspects of the dragon's movement, guaranteeing an accurate portrayal of its trajectory. Subsequently, the linear equation of the bench line was calculated, and the point - to - line distance formula was utilized to figure out the distance between the front handle of the dragon head and the bench line. This calculation was vital for evaluating potential collision risks.

To automate the collision detection process, the MATLAB program was set up to compare the computed distance with a pre - established safe distance. In the event that the measured distance was less than this threshold, the program would promptly identify a collision and note down the corresponding moment as the termination time of the dragon dance team's disk insertion. At the same time, the program would generate the position and velocity results of each node of the dragon dance team at this critical juncture.

This all - encompassing output made it possible to conduct a detailed examination of the system's behavior at the instant of collision, thereby finalizing the entire process of solving the collision equation. Through this well - structured approach, the experiment successfully merged theoretical modeling with computational analysis, offering useful perspectives on the kinematic behavior and safety factors related to dragon dance performances.

IV. Results

By meticulously leveraging MATLAB to solve the collision termination model, a significant finding emerged: the dragon dance team experienced a collision at a specific time point during the simulation, which ultimately led to the cessation of their spinning maneuver. This critical moment was not only a pivotal event in the simulation but also held the key to understanding the dynamic behavior of the dragon dance system under collision conditions.

Subsequently, the established kinematic model was employed to comprehensively solve for the position and velocity results of each node of the bench dragon precisely at the termination time. This involved a detailed analysis of the motion equations and the application of mathematical algorithms to calculate the exact state of each component at the instant of collision. The kinematic model, which had been carefully constructed based on geometric principles and physical laws, provided a robust framework for this in - depth analysis.

At the same time, to present the key data in a clear and organized manner, the positions of the front handle of the dragon head, along with the first, 51st, 101st, 151st, and 201st sections of the dragon body, and the rear handle of the dragon tail were systematically tabulated in Table 1. This table serves as a valuable reference, enabling researchers and practitioners to visually compare and analyze the spatial distribution of different parts of the bench dragon at the critical moment of collision. It offers a snapshot of the complex interplay between the various components and provides essential insights into the mechanics of the collision event, facilitating further studies on improving the safety and performance of dragon dance activities.

Table 1: The position and velocity results of a specific node at the termination time

Node	Horizontal axis x (m)	Vertical axis y (m)	Speed (m/s)
Dragon Head	1.810433	-1.159897	1.000000
Section 1 Dragon Body	0.971839	1.448196	1.010264
Section 51 Dragon Body	3.670619	1.638930	0.992779
Section 101 Dragon Body	-3.447495	-4.077236	0.990274
Section 151 Dragon Body	-2.224087	-6.229008	0.989269
Section 201 Dragon Body	-7.688064	2.967167	0.988727
Dragon Tail (Rear)	4.078297	6.736267	0.988560

Figure 7 shows the position results at the termination time, and Figure 8 shows the velocity results at the termination time. The horizontal axes 1, 2, 3, 4, 5, 6, and 7 in Figure 8 represent the nodes of the first dragon head, 1, 51, 101, 151, 201, and the tail (rear), respectively.

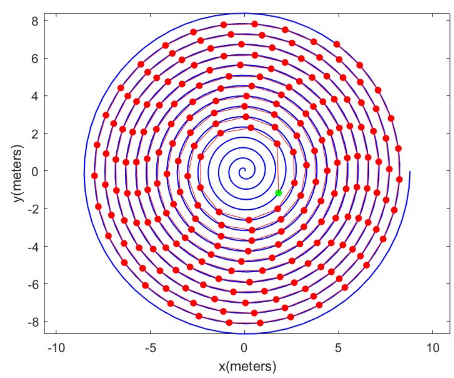

Figure 7: Position results at termination time

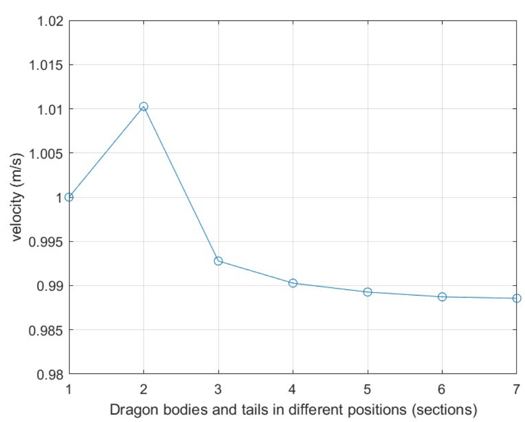

Figure 8: Velocity results at termination time

In the detailed analysis of the dragon dance team's motion simulation, several crucial observations emerge.

Firstly, at the specific time point of t=416s, a significant milestone was reached. The dragon dance team's leader, who plays a pivotal guiding role, entered the fourth circle, and concurrently, all members of the dragon dance team successfully transitioned into the spiral formation. This synchronized movement demonstrated the team's well - coordinated performance.

Secondly, an interesting velocity pattern was observed as the distance between the dragon body and the dragon head increased. The speed of the dragon body showed a gradually decreasing trend. This phenomenon can be attributed to the modeling approach. During the modeling process, we made an approximation by considering the length of the connection between the benches through holes as the arc length on the spiral. Since the calculation of arc length relies on the curvature of the arc, in reality, the length of the straight - line connection between the benches is shorter than the arc length within the same time frame.

As the distance from the dragon head grows, this length error accumulates. Consequently, the actual distance traveled by the rear part of the dragon body in the same time period becomes shorter, which is manifested as a decrease in speed. Finally, upon a detailed examination of Figure 5, a notable sudden change in velocity was discovered between the dragon head and the first dragon body. This abrupt speed variation is most likely the result of an initial error in the modeling process. When the dragon head and the first dragon body were modeled as two separate entities, it led to discrepancies in their initial conditions and motion states. These differences are particularly pronounced at the connection point, causing velocity discontinuities. Unfortunately, in the initial stages of modeling, this potential source of error was overlooked, highlighting areas for future model refinement.

V. Conclusions

This article delves into the kinematic characteristics and potential collision risks of dragon dance teams, employing a systematic approach that combines theoretical modeling, computational simulation, and empirical analysis. By defining a "safe distance" as a critical threshold for collision avoidance and constructing a collision termination model rooted in plane geometry and kinematic equations, the study accurately determines the termination time of the dragon dance team’s disk - insertion maneuver while analyzing the specific positions and velocities of each handle node in detail.

The results reveal that the velocity of the dragon body decreases progressively with increasing distance from the dragon head, a phenomenon closely tied to the model’s approximation of arc length calculation based on the Archimedean spiral trajectory. This finding not only verifies the rationality and stability of the kinematic model but also highlights the significant influence of the dragon head’s initial speed on the collision termination time, demonstrating the model’s sensitivity to key input parameters.

Beyond its contributions to dragon dance safety, this research establishes a methodological framework for studying kinematic problems in complex systems, integrating geometric modeling, recursive algorithms, and MATLAB - based numerical simulations. It provides a scientific foundation for optimizing performance safety by quantifying collision risks and motion dynamics, enabling practitioners to adjust movement parameters proactively.

Looking ahead, the study envisions expanding the kinematic model to three - dimensional space, incorporating real - time sensor data from inertial measurement units or optical tracking systems, and leveraging machine learning algorithms to predict collision times and optimize motion trajectories dynamically.

Such advancements aim to enhance the model’s practical applicability, allowing for real - time collision prevention and more fluid, safer dragon dance performances that balance tradition with technological innovation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

Data Sharing Agreement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

[1] Chen Yang, Gao Fengqiang Calibration of industrial robots based on kinematic models [J]. Journal of Changshu Institute of Technology, 2024,38 (05): 67-72.

[2] Li Yihui, Wu Jiajun, Guo Zhuohao Geometric inverse kinematics for nodal kinematic models [J]. Electromechanical Engineering Technology, 2024,53 (07): 87-92.

[3] Zhou Jia More on the simple collision theoretical model [J]. College Chemistry, 2023,38 (5): 261-264.

[4] Yao, Y., Criddle, C. S., & Fringer, O. B. (2021). Competing flow and collision effects in a monodispersed liquid-solid fluidized bed at a moderate archimedes number.
[5] Chen Xianjing, Wang Gang AOA based approximate unbiased positioning method in modified polar coordinate system [J]. Journal of Sensing Technology, 2020, 33 (10): 1467-1474.
[6] Bo, P., Mai, X., Meng, W., & Zhang, C. (2023). Improving geometric iterative approximation methods using local approximations. Computers & Graphics, 116, 33-45.
[7] Wang W, Zhao Y, Li Y. Design and dynamic modeling of variable stiffness joint actuator based on archimedes spiral[J]. IEEE access, 2018, 6: 43798-43807.
[8] Wen Jun, Yang Yang, Liang Zhenyu, etc Analysis of the uncertainty in measuring the radius of curvature of Newton's rings with chord length instead of diameter [J]. College Physics, 2024, 43 (09): 35-39.
[9] Zhou, X., Wang, Y., Zhu, Q. et al. Circle detection with model fitting in polar coordinates for glass bottle mouth localization. Int J Adv Manuf Technol 120, 1041–1051 (2022).
[10] Dong J. Research on Motion Path Optimization Based on Iterative Method and Geometric Reasoning[C]//2024 IEEE 2nd International Conference on Electrical, Automation and Computer Engineering (ICEACE). IEEE, 2024: 816-821.
[11] Huang J, Shi K. Research on Collision Detection and Path Optimization of Bench Dragon Motion[C]//Proceedings of The 4th International Conference on Computer, Internet of Things and Control Engineering. 2024: 134-138.
[12] Yang Huirong, Zhang Hongliang Research on deformation error compensation and reconstruction of hot rolled plate based on curvature integral algorithm [J]. Chinese Journal of Engineering Machinery, 2023,21 (03): 204-208.
[13] Yan Min, Liu Tao, Dang Xu, etc Full mesh high compression ratio Archimedes spiral vortex profile arc correction method [J/OL]. Journal of Jilin University (Engineering Edition), 1-8 [225-05-05].
[14] Tripathy T, Shima T. Archimedean spiral-based intercept angle guidance[J]. Journal of Guidance, Control, and Dynamics, 2019, 42(5): 1105-1115.
[15] Li Mengyao Using the formula of distance from point to straight line to solve algebraic problems [J]. High School Mathematics Teaching and Learning, 2024 (6): 30-3145.
[16] Ling Yunlong, Wang Chuan, Zhang Haichao Three wire circular magnetic guidance based on Archimedean spiral [J]. Acta Physica Sinica, 2020,69 (10): 107-115.
[17] Liu Tao, Li Yinping Research on the fitting algorithm of vortex profile based on equal error Archimedean spiral method [J]. Combination Machine Tool and Automation Processing Technology, 2019, (06):17-19.
[18] You Zhongtong, Wang Taiyong, Liu Qingjian, etc A discrete point spiral fitting algorithm based on least squares method [J]. China Mechanical Engineering, 2018, 29 (20): 2502-2506+2514.