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Modeling and Simulating Algorithms for Track of Direct Free-kick in Football Arc

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ABSTRACT. *The description of the sports state of soccer in sports is complicated. We analyze the force on the soccer's motion process from two angles of plane and curved surface respectively, and describe its motion track, especially the causes of soccer's arc motion, so as to explain the motion state of balls such as soccer. Football curve ball is also called "banana ball". In football matches, it can make it difficult for the defending side to make a correct judgment. Therefore, it has a fascinating overall effect in the competition and is a very popular technology in contemporary football technology. On the basis of literature review, the factors such as ejection angle, rotation and air resistance of arc ball are analyzed, and the stress process of football in flight is decomposed.A scientific model was established without considering other secondary factors, and the "hot zone" that can shoot the arc ball was analyzed, and the best shot area of the arc ball was given. At the same time, the football trajectory is simulated. The flight path of the curved ball is reproduced by input parameters to objectively determine whether the soccer ball hits the goal.*

KEYWORDS: *Football Curve; Direct Free-kick; Motion Trajectory; Modeling*

1. Introduction

Football is the world's most popular sport with millions of participants. Because it has received such extensive attention, many people have been studying the technologies involved[1]. Of the 171 goals in the 1998 World Cup, 42 were set goals, of which 50% were direct free kicks, thus showing the role of an accurate free kick in football. Beckham is good at banana ball, while Cristiano Ronaldo is good at falling the ball in front of the goal or landing the rebound ball[2]. All these make us cannot help studying the wonderful phenomenon of curling in the football world. When we are playing football, the soccer ball, after receiving the force that does not pass through the center of gravity, then rotates and flies in a curve in the air[3]. This is called arc ball, also known as "banana ball"[4]. The left deviation of the ball from the normal orbit is called "left-hand" and vice versa. Curved balls are usually kicked out on the medial instep and the lateral instep[5].

In recent years, many experts and scholars have developed a strong interest in this technology[6]. In a ball sports project, when the ball moves in the air, it is often accompanied by rotation, and the rotation of the ball itself necessarily affects the trajectory of its movement. In other words, in this case, the Magnus effect needs to be considered[7]. The arc ball in the football game has a significant effect on the Magnus effect. In the current game, the arc ball is generally used to improve the hit rate[8]. Therefore, the direct free kick in the arc will be the research object, and the better kicking point will be analyzed. By studying the arc ball in football, the force of the rotating sphere in the air is analyzed. Simplify the football, model the football trajectory according to the parameters, analyze the better area of the direct free kick kicking out the arc, and discuss with the actual situation[9]. At the same time, the football trajectory is changed by constantly changing the parameters. Judging whether to hit the goal, providing a theoretical basis for the football player to kick a high-quality, high-scoring direct free kick[10].

2. The Theoretical Basis of the Curve Movement of Football

2.1 Mechanics Principle of Curving Ball in Football

According to the law of rotation, when an object rotates around an axis, the vector sum of its torque to the axis must not be zero. The force of kicking a ball does not pass through the center of the ball, that is, the eccentric force. Because the resultant force can be decomposed into normal force, making the ball translate. Tangential force turns the ball. The fast and slow rotation of the ball depends on the size and direction of the kicking force. When the force is constant, the faster the ball rotates, but the reverse force decreases correspondingly, and the horizontal speed of the ball also decreases. This situation is not conducive to long-distance passing in the match.When the direction of the resultant line of action is constant, the greater the force, the faster the ball's rotation speed and flight speed. Therefore, the power of playing is very important. The standard ball moment of inertia for the game is constant, so the greater the moment, the greater the angular acceleration. From the above analysis, we can see that the force line does not kick the football through the center of the center of the ball, it is with a strong rotation. This kind of ball with a rotating sphere flying in the air, rotating at a high speed, makes it close to the air particles of the ball skin, and rotates to form a circulation layer, which rotates with the ball.

2.2 Magnus effect

Most of the current college physics textbooks take particles as the research object when discussing the oblique projectile motion, and seldom involve the oblique projectile motion of rotating objects. In fact, the motion of rotating projectile is a very common phenomenon. Especially in ball games, when the ball is in air movement, it often rotates with itself. For example, soccer, table tennis, basketball, tennis, etc. However, the rotation of the sphere itself will inevitably affect the trajectory of its motion, that is to say, in this case, Magnus effect needs to be considered.When a cylinder rotates about its own axis and fluid flows in a direction perpendicular to the axis, it is subjected to a lateral force perpendicular to the flow direction. The direction of the force is always directed to the same side from the side opposite to the linear velocity on the cylindrical surface. This phenomenon is called the Magnus effect. In fact, the Magnus effect is not limited to a rotating cylinder. The so-called "banana ball" in football matches, the arc ball in the table tennis match and the ball-cutting technique all have a significant effect on the Magnus effect.

3. Factors Influencing Football Goals

3.1 Projection angle factor

There are many factors that affect the flight path of football. Such as kick technique, rotation, firing angle, kick position, etc. There are also wind speed, air temperature, humidity and other weather factors. In addition, the physical characteristics of the football, such as roughness, quality, number of pieces of skin that make up the surface of the ball, material and inflation pressure, will also affect the flight trajectory of the football. Under ideal conditions, the model is established without considering the influence of external factors, but these factors sometimes play a vital role in the actual kick training. Therefore, these factors should be taken into account.For example, an object of mass m has a greater influence on the maximum range throw angle in the range of less than 3 kg, and the effect is less pronounced after more than 3 kg. As the mass m increases, the projection angle is finally 45°. In addition, under the same conditions, the upper spiral has a low arc, a fast drop, and a near drop point. The lower spin is flying at a high arc and the drop point is far, and no rotating ball is in between. This is due to the presence or absence of key factors in the model with different lift and lift directions.

3.2 Air resistance factor

The magnitude of air resistance is related to the velocity of the object relative to the air and the shape of the object. In general, the air resistance of the flying body is proportional to the air density, the surface area of the flying body and the waiting speed, and inversely proportional to the smoothness of the surface of the flying body. The streamline shape of the flying body also affects the resistance. The better the streamline shape, the smaller the resistance. The pressure difference caused by the rotation of "banana ball" is called lift. It is related to the motion speed and rotation frequency of the sphere and is expressed by the following equation (1).The ball speed is a variable that is full of variables and difficult to determine. The first thing to note is that since the lift is perpendicular to the ball speed, the presence of lift has no effect on the magnitude of the ball speed. Secondly, because of the existence of the ball speed, the air resistance occurs, and the air resistance in turn causes the ball speed to change. The flight path of the ball is deviated from the arc shape, and the actual trajectory depends on how the speed changes. Air resistance is a dynamic quantity that is related to the shape of the object, the speed of motion, and the surface characteristics.

$$R_i = M_i \sum_{i=1}^{N_r} \hat{R}_{i,r} \tag{1}$$

Where Ri is the lift coefficient, Nr is the air density, r is the diameter of the ball, I is the ball rotation frequency, and Mi is the ball speed. It is Ri that makes the ball move in an arc.

4. Arc Motion of Football in Plane and Surface

4.1 The Curve Movement of Football in Plane

The wonderful football match ended slowly and many classic pictures still appeared in front of the fans. One of the classics is the beautiful arc when a star shoots. Are you eager to try? As long as your hitting leg accelerates forward, the longus hallucis muscle fastens to the ankle. Keep your feet straight. Pay attention to your toes when hitting the ball. The thigh naturally swings to the vertical and the calf swings to a large extent. Make full use of waist and abdomen strength to hit the lower side of the ball with the instep. The line of action of the force deviates from the center of the ball when hitting the ball. When the football flies from your feet, it will draw a beautiful arc in the air. Why do you play curling when playing football? In the past, people usually started from the ideal plane motion to analyze the force on the soccer ball. Here, they further carried out qualitative force analysis from two aspects of plane and curved surface to describe its motion trajectory.

Force F plays soccer. The line of force passes through the center of the soccer ball. The soccer ball flies forward at speed V. Due to the viscosity of the air, the air near the football surface is driven to flow. Air has a backward speed relative to football, which is different from the forward speed and the backward speed of flying football. The front velocity is smaller than the rear velocity, causing the front air pressure and the rear air pressure to be different. Their pressure difference acts on the spherical surface of the soccer ball, making the soccer ball subject to pressure drag. Ignoring the fact that the effect of the gas height difference before and after the football is not significant, according to Bernoulli equation (2), the pressure difference acts on the effective area of the ball surface of the football, and its direction is along the opposite direction of the flying direction of the football, thus hindering the flying football. The size of the pressure drag is related to the difference in air velocity between the front and rear surfaces of the flying soccer ball. The difference in air flow rate changes the pressure difference, thus changing the size of the pressure drag. From the above analysis, it can be seen that football is affected by pressure drag and its own gravity during flight.

$$V = \sqrt{\frac{F \times Vt}{K} + \frac{F^2}{4 \times K^2}} + Vt + \frac{F}{2 \times K} \tag{2}$$

The flying football generates a vertical acceleration of gravity under the action of gravity, and produces a tangential acceleration in the horizontal direction under the action of the differential pressure resistance. The combination of the two accelerations causes the motion of the football to be a curve motion in the plane K, so the football does not turn into an arc motion within the curved surface.

4.2 Curve Motion of Football in Surface

If the line of action of the force deviates from the center of the ball, the force can be translated to the center of the ball. At this time, the football is equivalent to the combined action of the force passing through the center of the ball and the force generating a moment to make the football rotate. When this force acts on the lower left side of the soccer ball, the soccer ball will fly in the air at an initial speed along a direction at an angle with the plane clip. At the same time, the ball rotates counterclockwise at a certain angular velocity. If this force acts on the lower right side of the football, the football will rotate clockwise. The rotation of the soccer ball and the viscous effect of the air cause the circulation of the air on the surface of the soccer ball, and the circulation rate is consistent with the rotation direction of the soccer ball.When the ball is flying forward at a relative speed, the air flow flows backward at a certain speed with respect to the soccer ball. According to the Bernoulli equation, according to the following equation (3), if the effective area of the pressure difference acting on the soccer sphere is S, then the magnitude of the force the football receives is F, that is, the football is subjected to the lateral force F. Lift. As mentioned above, the airflow velocity component is different in the front and rear speeds of the flying soccer ball, so that the soccer ball is subjected to the pressure difference resistance.

$$R_j = \frac{f_{ij}}{Tj} \times S_j \tag{3}$$

It can be seen from this that the flying football will be affected by the combined force of lift, pressure drag and gravity.

5. Optimal Modeling and Simulation of Track of Direct Free-kick in Football Arc

5.1 Optimization of Basic Model for Track of Arc Directly Arbitrary Sphere

During the translational flight of a soccer ball, it is only affected by gravity and air resistance, which causes the ball speed to decrease. Curved direct free kick flies in rotation, not only under the action of gravity and air resistance, but also under the differential pressure perpendicular to the flight direction. The initial trajectory of soccer is slightly curved and gradually increases. Ge Longqi analyzed the forces on football and established a basic model (4). The right-angle coordinate axis is established vertically upward, and the axis is along the original advancing direction. The axis represents the lateral offset.Let the ball of mass m be kicked out at a certain initial speed and rotated around the axis passing through the center of the ball at x as the initial rotational angular velocity, and the basic model of the motion law of the ball is obtained. In addition, the modeling optimizes the football direct free-ball trajectory base model (4). The optimization model scheme (5) adds the displacement in the i-axis direction and the influence factors of the horizontal initial velocity and the x-direction declination. The situation discussed in the base model is limited to horizontal displacement, which is clearly not realistic.

$$p_{ij} = x_{ij}^{'} / \sum_{i=1}^{m} x_{ij}^{'} \tag{4}$$

$$B(\vec{X}) = \prod_{i=1}^{m} (f_i(\vec{X}) - f_i(\vec{X}_w))^{1/m} \tag{5}$$

Based on the above analysis, the vertical displacement needs to be added to the basic model, which is treated as a vertical upward throwing motion here.

5.2 Simulation of football trajectory model

For curved direct free kick, this paper first gives a more general description of the three-dimensional motion track of curved free kick, giving a more intuitive understanding of curved direct free kick. Firstly, a kick center is created, and the basic model is used to simulate the football in three directions. In order to know which part of the football field the arc direct free kick hits better, first divide the football field half into uniform grids and establish the origin of coordinates. Grid intersections are set as kick points and 4 parameters are set. Initial velocity, angular velocity and kick point. Since no free kick can be kicked in the small restricted area and the pitch is symmetrical, the kick point is only considered in a certain dark shaded area. According to the model established by the optimization scheme, through the constant change of the parameters in a certain range of values, we can get at which points the scoring rate of arc-line direct free kick is the highest, which is what we call the hot zone, and get its coordinates. Then import coordinate data and draw contour lines of the hot zone.

In addition, three-dimensional simulation of the direct free-arbit trajectory of the arc is performed, and it is determined whether or not the goal is scored by inputting different parameters. The specific operation is as follows. Simulate a soccer field and a soccer ball, and realize the three-dimensional simulation by presenting different perspectives of the soccer field simulation interface by changing the parameters “azimuth” and “top view angle”. Set the parameters of the kick point and the parameters of the ball trajectory. The parameters are the translation speed, the rotation speed, the angle between the translation speed and the axis, the angle between the horizontal speed and the axis, and the initial coordinates. By changing the parameters, the trajectory of the football is determined and whether or not the goal is scored. At the same time, add the tick options “Show Motion Track” and “Pre-Retention Track” to achieve more user-friendly operation options. Add model selection blocks, such as base models and other optimization scheme models. Three models can be arbitrarily selected for soccer trajectory simulation, and the comparison of football trajectories under different scheme models is realized. Set the “Simulation” button and click to run the football track.

5.3 Training of Curving Ball in Football

In order to ensure the effectiveness of the curve ball in the competition, it is required that the curve ball kicked should not only have sufficient flying distance, but also have strong rotation. To this end, the following teaching methods should be adopted in learning and training. First of all, students (or athletes) should be given a theoretical explanation of the mechanics principle. In order to ensure that the kicked ball has a strong rotation, they should practice kicking the rotating ball on the basis of mastering the inside and outside of the instep. For example, when kicking a ball with the inside of the instep, there are three main points of action. Kicking feet should hit the back and outside of the ball, manic joints should be turned inward and feet should be slightly tilted upward. If you use the outside of the instep to kick the ball, pay attention to the toe turning inward, the toe fastening downward, and the instep stretching straight. The above two kicking methods must have the “rubbing ball” action to make the ball rotate. After practicing skillfully, we should exert more force to make the ball have enough forward initial speed and the swing range of the foot is larger, and the kick leg should have the feeling of “sending out” the ball along with the kick direction, so as to ensure the rotation speed of the football.

By analyzing and establishing a reasonable and effective mathematical model, we use the contour map to show the better area to kick the arc direct free kick. At the same time, through the analysis of the curve ball, the soccer movement track is drawn and the simulation model of the soccer track is completed. By inputting various parameters and using the established model, the running track of this kind of curve ball is displayed to judge whether to score a goal. Although the arc direct free kick, the “hot spot” of the kick point and the three-dimensional plane of the direct free kick are simulated, there are many factors that affect the football flight path in real life, and there is still room for improvement. For example, it is possible to increase the analysis of the influencing factors of football, such as weather conditions, kicking skills, and the physical characteristics of football.

6. Conclusion

Flying soccer balls generate vertical gravitational acceleration under the action of gravity, horizontal tangential acceleration under the action of pressure drag, and horizontal normal acceleration under the action of lift. The combined acceleration of gravity acceleration and tangential acceleration makes the football move in a curve in the plane P', while the reverse acceleration makes the football no longer move in a curve in the plane P', which urges the football to turn left. Therefore, on the lower side of football, the line of action of force deviates from the center of the ball, and the kicked football will draw a beautiful arc in the air.In this paper, a reasonable and optimized mathematical model is established by analysis, and the contour map is used to show the better area of the direct free kick of the kick line. Through the analysis of the arc ball, the trajectory of the football is drawn, and the simulation model of the football trajectory is completed. Using the established model, the trajectory of such a curved ball is described to determine whether or not to score. According to the obtained better area of the goal and the modeling and simulation of the input parameters, the purpose of improving the goal of the athlete is achieved.

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