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Study on the relationship between arc and velocity of soccer shot based on polynomial fitting calculation

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Abstract The law and development trend of soccer determines the importance of the strength quality of soccer players, and the strength quality plays an important role in the development of other qualities, and the strength quality is the fundamental for soccer players to improve the level of sports technology and special performance. In this paper, firstly, the force of the soccer ball and the factors affecting the flight trajectory of the soccer ball are described, the force process of the soccer ball in flight is decomposed, and the optimization model is established and solved without considering other secondary factors, and then the simulation of the soccer ball's goal speed is carried out, and the correlation and regression algorithms are used to explore the multivariate regression analysis affecting the curvature and speed of the soccer ball's shot. The results of the study show that the closer to the goal, the higher the shooting rate; while close to the left and right edges of the goal and the two corners, the shooting rate is almost 0. The relative size of the probability of scoring a goal with or without the Magnus effect shows an alternating banded radial distribution. The four factors, ball initial height, ball off hand height, wrist joint speed and knee joint speed, had the greatest effect on the hit rate in different distance shots through the arc of the shot and the speed of the shot.

Index Terms soccer shooting mechanism, motion trajectory, multiple regression, influencing factors

I. Introduction

Soccer, with the reputation of “the world's first sport”, is the most influential single sport in the global sports world [1], [2]. Soccer shooting is a professional term for soccer games, which mainly refers to the use of kicks, headers, shovels and other techniques to shoot the ball to the opponent's goal [3], [4]. In soccer, goal shooting is the ultimate goal of offense, the means of scoring, and the key to win or lose the game [5], [6]. At the same time, there are many methods of goal shooting, such as shooting against ground balls, air balls, bouncing balls, straight-line balls, curved balls, which can be shot directly, with a shot, catching a shot and so on [7]-[9]. Soccer curved ball is a common technical action in soccer games, and it is also a skill that many players are good at [10], [11]. This technique not only affects the speed of the soccer ball in the game and helps players to break through the opponent's goal, but also brings visual enjoyment to the audience [12], [13].

The curved path of a soccer ball curved ball is produced by a combination of lateral and lift forces generated by the soccer ball during its flight [14], [15]. As the soccer ball rotates, the airflow over the surface of the ball varies in velocity, creating an airflow velocity gradient [16]. According to Bernoulli's law, the air pressure decreases where the airflow velocity is greater and increases where the airflow velocity is less [17], [18]. As a result, a low air pressure is generated on one side of the soccer ball and a high air pressure on the other side, thus creating a lateral force [19]. At the same time, the rotation of the soccer ball will also produce a lift force, which makes the soccer ball produce an upward force in the process of flight, which is the curve motion produced by the soccer ball in the process of flight, and the greater the curvature of the soccer ball's speed will decrease accordingly, which can be controlled by controlling the curvature of the speed, thus greater to improve the rate of goal scoring [20]-[22].

The study first analyzes the force of soccer ball in the process of movement and the influencing factors of soccer ball shooting. On this basis, the basic principle of recovery coefficient and aerodynamic analysis method are introduced, and then the optimization model is established under the condition of not considering other factors, and at the same time, the relational equation between the minimum projection angle, the initial velocity of the shot and the angle of incidence is determined. Based on Monte Carlo algorithm to find out the conditions and distribution range satisfied by the initial velocity when it can reach the effective goal. On this basis, the goal probability distribution graph of the whole penalty area is analyzed. Based on the parameters of linear and angular velocities of the body-related joints during the shooting process in soccer players' long-distance, overhead and curved ball shots, correlation and regression analyses are applied to explore the influencing factors.

II. Kinematic analysis of soccer shot trajectories

II. A. Analysis of forces on a soccer ball in flight

II. A. 1) Theoretical analysis and calculation of air resistance

An important force that the soccer ball is subjected to during its flight, air resistance, should not be ignored, it is the obstruction force of the air on the ball during its flight, the following first discusses the basic theory of air resistance.

Starting from the flat plate in the air by the pressure difference resistance to study, and then study the sphere of the air resistance formula. Assuming that the airflow which has not yet reached the flat plate is called state 1, and the airflow which has reached the flat plate is called state 2, then according to Bernoulli's principle there is $p_1 + 1/2\rho v_1^2 = p_2 + 1/2\rho v_2^2$, with p being the pressure energy of the airflow per unit volume, where $v_1 = v$ (i.e., the motion of the flat plate) and $v_2 = 0$, then $p_1 - p_2 = 1/2\rho v^2$ [23]. If the back of the plate is considered to be subjected to an air pressure equal to the pressure p_1 at state 1 in the front, the difference in pressure between the two sides of the plate multiplied by the area A of the plate gives the resistance F_d:

$$F_d = (p_1 - p_2)A = 1/2\rho A v^2 \tag{1}$$

The above formula is not the final expression to be used, because it should also be taken into account that the gas mass in the flow to the plate completely lose velocity, around the plate to flow backwards, obviously this time p_2 to be reduced, after the plate of p_1 also change, and the gas flow through the surface will appear frictional resistance and more complex forms of other air resistance. Therefore, to get a more accurate resistance expression should introduce a resistance coefficient C_d, then the above equation becomes as shown in equation (2):

$$F_d = 1/2C_d\rho A v^2 \tag{2}$$

where C_d is the coefficient of air resistance, A is the cross-section of the ball, ρ is the density of the air (usually taken as 1.20 at sea level), and v is the speed of the ball.

From the above formula, it can be seen that the size of the air resistance is very much related to the speed of the object relative to the air, the shape of the object and so on. Generally the greater the speed of the object, the greater the air resistance; the greater the air density, the greater the resistance, the size of the resistance is directly proportional to the air density, the air density increases, the air flow through the body of the kinetic pressure change is large, so the flight body up and down the pressure difference and before and after the change in the pressure difference is also large; resistance is directly proportional to the area; the smoother the surface of the aircraft, the lower the frictional resistance; the rougher the surface of the body of the flight, frictional resistance is The smoother the surface of the airplane, the lower the frictional drag; the rougher the surface of the airplane, the higher the frictional drag; the more streamlined the shape of the airplane, the lower the drag.

II. A. 2) Magnus Effect on Ball Lift

Since a rotating soccer ball will be subjected to a lift force during flight due to the Magnus effect, and the force is a force that has an important effect on the arc of flight of the soccer ball, it will be analyzed and introduced here first.

Magnus discovered through experimental observation that a cylinder or sphere in parallel flow will be subjected to a lateral force perpendicular to the direction of incoming flow when it rotates around its axis. This phenomenon came to be known as the Magnus effect. It can be seen that the soccer ball in flight because of its axis of rotation and the direction of movement of the ball v perpendicular to the direction of motion, then due to the velocity above the ball and the direction of the air flow is opposite to the direction of the air flow, resulting in a decrease in the velocity of the air at that place, the density increases, the pressure increases; and below the ball is the same as the direction of the air flow. The air there is faster, less dense and less pressurized than above the ball [24]. From Bernoulli's principle, the pressure of the upper gas is greater than the pressure of the lower gas, so the gas exerts a net downward pressure on the ball, and the motion of the ball deviates from its original trajectory to produce an arc motion.

The pressure difference in the ball in the air due to rotation is called the lift force F_l, which is related to the speed and rotational frequency of the sphere motion: it is expressed by equation (3):

$$F_l = C_l \rho D^3 f v \tag{3}$$

where C_l is the lift coefficient, the value of which is different for different shapes, it is found that the value of C_l for soccer ball is more appropriate at 1.23; D is the diameter of the sphere; and f is the rotational frequency of the sphere which is taken as 10 rad/s. The main factors affecting the magnitude of lift are speed and air density, area and surface mass.

The main factors affecting the amount of lift are speed and air density, area, shape and surface mass. The greater the flight speed the greater the lift. Theoretically, the lift is proportional to the speed of flight, i.e., the speed is doubled, the lift is increased, and the lift is increased.

II. B.Recovery coefficients and aerodynamic modeling

Soccer is a collision-based sport whose main principles are physics collision, mathematics parabola and kinematics, and soccer collision obeys the coefficient of recovery (COR) principle. When an external force acts so that the soccer ball collides with the basketball board, the ground of the stadium or the human body, the impulse of the collision in the contact time t_0 to $t_0 + \Delta t$ can be defined as:

$$F_{ei} = \int_{t_0}^{t_0+\Delta t} F_{ef} dt \tag{4}$$

where: F_{ei} is the impulse at the time of collision; F_{ef} is the external force.

From equation (4), when two objects collide, they are categorized into elastic collision, inelastic collision and fully elastic collision due to the different recovery coefficients, which can be defined as in elastic collision:

$$e_{COR} = \frac{u_2 - u_1}{v_2 - v_1} \tag{5}$$

where e_{COR} is the coefficient of recovery; u_1, u_2 is the normal component of the velocity along the collision surface after the collision of the two objects; and v_1, v_2 is the normal component of the velocity along the collision surface before the collision of the two objects. When the collision is elastic, $e_{COR} \in (0,1)$.

When the ball is collided, the corresponding linear and angular velocities are generated instantly and are acted upon by the resistance of the air: a collided ball moving in the air is acted upon by two forces, namely, the air resistance and the ball's own gravitational force, which causes the curve of the ball's motion to change. When a soccer ball of mass m_l is moving through the air, it is subjected to air resistance:

$$F_{ar} = \frac{1}{2}\rho_a \cdot S_{ra} \cdot k_{rc} \cdot v_a^2 \tag{6}$$

where: F_{ar} is the air resistance of the ball movement; ρ_a is the density of the air (at a temperature of 25 ℃, pressure 1.01325 × 105Pa, ρ_a = 1.185kg/m³); S_{ra} is the cross-sectional area of the ball; k_{rc} is the coefficient of air resistance; v_a is the velocity of relative motion between the ball and the air.

A soccer ball is thrown and immediately moves through the air, where it is acted upon by the forces imparted by the air. If the soccer ball is thrown and rotates counterclockwise in the air, the air around it rotates counterclockwise. The air flow in the upper part of the soccer ball is accelerated, which reduces the air pressure, while the air in the lower part of the soccer ball rotates clockwise, which reduces the air flow and increases the air pressure. Therefore, the pressure difference between the upper and lower parts of the moving soccer ball results in an upward force, which can be described as:

$$F_{lf} = \frac{1}{2}\rho_a \cdot S_{ra} \cdot k_{lf} \cdot v_a^2 \tag{7}$$

where: F_{lf} is the air lift force on the soccer ball; k_{lf} is the coefficient of lifting force of the steel-free quantity, whose value depends on the speed of the soccer ball, the rotation rate, and the characteristics of the surface of the soccer ball. The value of k_{lf} is dependent on the soccer ball speed, rotation rate and surface properties of the soccer ball. k_{lf} is also related to the angular velocity of the soccer ball rotation, so the coefficient of lift can be defined as:

$$k_{lf}^{'} = \frac{v_a \cdot k_{lf}}{r_l \cdot \omega_l} \tag{8}$$

where: r_l is the radius of the soccer ball; ω_l is the angular velocity of rotation of the soccer ball in the air. Thus, Eq. (8) can be rewritten as:

$$F_{lf} = \frac{1}{2}\rho_a \cdot r_l \cdot \omega_l \cdot S_{ra} \cdot k_{lf}^{'} \cdot v_a \tag{9}$$

In addition, a soccer ball moving through the air will be subjected to the buoyant force of the air, the magnitude of which can be described as:

$$F_{bf} = \rho_a \cdot g \cdot V_l = \frac{4}{3} \cdot \pi \cdot \rho_a \cdot g \cdot r_l^3 \tag{10}$$

where: ρ_a is the air density; g is the acceleration of gravity; and r_i is the radius of the soccer ball.

II. C.Factors affecting soccer shooting

II. C. 1) Projectile angle factor

An object of mass m has a large effect on the maximum range angle of projection θ in the range of less than 3 kg, and the effect is less pronounced after more than 3 kg, until the angle of projection eventually reaches 45° as the mass m increases.

II. C. 2) Rotation factors

Under the same conditions, the topspin ball flies with a low arc, falls fast, and lands close, while the bottomspin ball flies with a high arc and lands far, and the no-spin ball is in the middle of the two, which is caused by the key factors of the presence or absence of lift and the different directions of lift in the model.

II. C. 3) Air resistance (velocity) factors

The magnitude of air resistance is related to the velocity of the object relative to the air, the shape of the object and so on. In general, the size of the air resistance of the flying body and the air density into the surface area of the flying body to be speed is proportional to the smoothness of the surface of the flying body is inversely proportional. The streamlined shape of the flying body also affects the magnitude of the drag, the better the streamline, the lower the drag.

III. Modeling and Solving Soccer Shot Arc and Velocity

III. A. Optimization and modeling of direct free kick trajectories in soccer arcs

III. A. 1) Basic modeling of direct free kick trajectories in arcs

The soccer ball is subjected to only gravity and air resistance during its translational flight, and air resistance causes the ball's speed to decrease. The curved direct free kick is rotating flight, which is not only subject to gravity and air resistance, but also subject to the pressure of velocity difference perpendicular to the flight direction, resulting in a small degree of curvature of the initial trajectory of the soccer ball, and gradually increase. Gronkowski analyzed the forces acting on the soccer ball during its motion and developed a basic model.

Establish right-angle coordinates with the oz -axis vertically upward, the ox -axis along the original direction of advance, and the $o\gamma$ -axis representing the lateral offset. Let the ball with mass m be kicked in the $ox\gamma$ plane with initial velocity v_0 and rotate around the axis passing through the center of the ball with w_0 as the initial rotational angular velocity, to derive the basic model of the ball's law of motion:

$$x = \frac{mv_0}{Gw_0} \sin \frac{Gw_0}{m} t \tag{11}$$

$$y = \frac{mv_0}{Gw_0} (1 - \cos \frac{Gw_0}{m} t) \tag{12}$$

III. A. 2) Optimized modeling of the base model

Optimizing the air resistance factor (viewing the motion of the soccer ball as a low-speed motion). When the movement of the soccer ball is viewed as a low-speed movement, air resistance $F = \frac{1}{2} c\rho AV$ (c for the air resistance coefficient, ρ for the density of air, normal dry air can be taken as 1.293g / l, special conditions can be monitored in the field, A for the object windward area, V for the object and the air relative speed of motion), the introduction of the coefficient $k = \frac{1}{2} c\rho A$, get $F = kV$.

The force in the z -axis direction of motion is:

$$z = \int_0^t v_h dt \tag{13}$$

Since the ball moves with: $\frac{dv_h}{dt} = -g - kv_h$, and the initial velocity in the vertical direction is set to be v_{h0} , we can obtain an expression for the velocity v_h in the vertical direction:

$$v_h = \frac{e^{-kt+\ln(g+kr_{k0})} - g}{k} \tag{14}$$

Substituting (13) into equation (14) yields the analytical equation for the displacement motion of the soccer ball:

$$z = -\frac{\frac{g}{e^{it}} + kgt + \frac{kv_{h0}}{e^{kt}} - g - kv_{h0}}{k^2} \tag{15}$$

Since the value of v_h can take a positive or negative value by the change of t, the rising and falling phases of the corresponding soccer ball are obtained. Thus substituting $v_h = 0$ into equation (15) yields:

$$t_1 = \frac{\ln(1 + \frac{kv_{h0}}{g})}{k} \tag{16}$$

It can be obtained that the soccer ball is in the ascending period of $(0, t_1)$ and in the descending period of (t_1, t). The horizontal direction is:

$$m\frac{dv}{dt} = -kv \quad \text{(Horizontal tangential)} \tag{17}$$

$$m\frac{v^2}{r} = Gwv \quad \text{(Horizontal normal direction)} \tag{18}$$

Integrate equations (17) and (18) and use the initial conditions to determine the constant of integration to obtain the law of motion of the rotating ball.

Integrate equation (17) by: $\int \frac{dv}{v} = -\frac{k}{m}\int dt$ to obtain:

$$\ln v = -\frac{k}{m}t + C \tag{19}$$

Substituting the initial conditions $t = 0, v = v_0$ into Eq. (19), we solve $v = e^{-\frac{k}{n}+\ln r_0}$ since $ds = vdt$, and we have:

$$s = \int e^{-\frac{i}{m}t+\ln t_0} dt = \frac{m}{k}e^{\ln t_0} - \frac{m}{k}e^{-\frac{i}{m}t+\ln t_0} \tag{20}$$

Considering $ds = rd\theta, r = \frac{ds}{d\theta} = v\frac{dt}{d\theta}$, substituting this into equation (18) yields $\frac{d\theta}{dx} = \frac{G}{m}w$, thus we have

$$\theta = \int_0^\theta d\theta = \int_0^t \frac{G}{m}wdt = \frac{G}{m}wt = \frac{G}{m}w_0 t \tag{21}$$

where w_0 is the initial rotational angular velocity. Up to this point, the law of motion of the ball can be obtained:

$$x = \int v_x dt = \int v\cos\theta dt = \int e^{-\frac{k}{m}+\ln t_0} \cos(\frac{G}{m}w_0 t)dt \tag{22}$$

$$y = \int v_y dt = \int v\sin\theta dt = \int e^{-\frac{k}{m}+\ln t_0} \sin(\frac{G}{m}w_0 t)dt \tag{23}$$

Solution:

$$x_0 = -(\frac{me^{\ln x_0 - \frac{k}{m}}(k\cos\frac{Gw}{m}t - Gw\sin\frac{Gw}{m}t) - mke^{\ln x_0}}{G^2w^2 + k^2}) \tag{24}$$

$$y_0 = -(\frac{me^{\ln x_0 - \frac{k}{m}}(k\sin\frac{Gw}{m}t - Gw\cos\frac{Gw}{m}t) - mGwe^{\ln x_0}}{G^2w^2+k^2}) \tag{25}$$

Combined with the optimization of the original scheme to include the angle of declination θ of the horizontal velocity with respect to the x direction, the formula can be obtained as:

$$x_{00} = y_0\sin\theta + x_0\cos\theta \tag{26}$$

$$y_{00} = y_0\cos\theta - x_0\sin\theta \tag{27}$$

Combine (17), (18), (26), and (27) to model and simulate.

III. B. Model solving

III. B. 1) Projection radius

The trajectory of the soccer ball can be regarded as a parabola, may be set to $f(x) = ax^2 + bx + c(a \neq 0)$ then, there:

$$\begin{cases} f(0) = c = h \\ f(L) = aL^2 + bL + c = H \\ f^{'}(0) = b = \tan\alpha \end{cases} \Rightarrow \begin{cases} a = \dfrac{H-h-L\tan\alpha}{L^2} \\ b = \tan\alpha \\ c = h \end{cases} \tag{28}$$

So the trajectory of the soccer ball corresponds to the function:

$$f(x) = \frac{H-h-L\tan\alpha}{L^2}x^2 + x\tan\alpha + h \tag{29}$$

For a soccer ball to be successfully shot into the goal, $L > -\frac{\tan\alpha}{2\cdot\frac{H-h-L\ \tan\alpha}{L^2}}$ must be satisfied to solve for $\tan\alpha > \frac{2}{(H-h)}L$, the angle of projection:

$$\alpha > \arctan\frac{2(H-h)}{L} \tag{30}$$

Obviously, when the distance L from the goal is kept constant, the greater the height h of the soccer ball when shooting, the smaller the projection angle α required for the soccer ball to be thrown into the goal.

III. B. 2) Relationship between the initial velocity of the hand and the arc of projection

Assuming that the initial velocity of the soccer ball when it is kicked is v_0, the acceleration of gravity is g, and the time elapsed from the time the soccer ball is kicked out to the time it enters the goal is t, the following conditions must be satisfied in order for the soccer ball to be successfully put into the goal:

$$\begin{cases} L = v_0 t\cos\alpha \\ H - h = v_0 t\sin\alpha - \dfrac{1}{2}gt^2 \end{cases} \tag{31}$$

Eliminating the time t gives:

$$v_0^2 = \frac{gL^2}{2(L\tan\alpha - H + h)\cos^2\alpha} \tag{32}$$

Transform the above equation into a quadratic equation about $\tan\alpha$:

$$gL^2\tan^2\alpha - 2Lv_0^2\tan\alpha + gL^2 + 2v_0^2(H-h) = 0 \tag{33}$$

The sufficient condition for this equation to have a real root is $\Delta = (-2Lv_0^2)^2 - 4gL^2[gL^2 + 2v_0^2(H-h)] \geq 0$, i.e. $v_0^4 - 2g(H-h)v_0^2 - g^2L^2 \geq 0$. Solving for this, the

$$v_0 \geq \sqrt{g\left[H-h+\sqrt{L^2+(H-h)^2}\right]} \tag{34}$$

So, the minimum initial velocity of the soccer ball at the time of strike is:

$$v_{0\_\min} = \sqrt{g\left[H-h+\sqrt{L^2+(H-h)^2}\right]} \tag{35}$$

At this point equation (33) has a unique solution:

$$\tan\alpha = \frac{H-h+\sqrt{L^2+(H-h)^2}}{L} \tag{36}$$

To wit:

$$\alpha = \arctan\frac{H-h+\sqrt{L^2+(H-h)^2}}{L} \tag{37}$$

III. B. 3) Relationship between radius of projection and radius of incidence

As the soccer ball is about to enter the goal line, the soccer ball can no longer be regarded as a prime point. At the moment the soccer ball enters the goal line, its trajectory can be approximated as a uniform linear motion into the goal. For the soccer ball flying obliquely over, its incident cross-section should be the projection of the goal in the direction perpendicular to the incident velocity of the soccer ball, for a rectangle. When the radius of the goal is R and the radius of the soccer ball is r, the long half-axis of the rectangle is $a = R$ and the short half-axis is $b = R\sin\beta$.

In order to make the center of the soccer ball through the center of the goal, must be satisfied that the short axis of the incident cross-section $2b$ is not less than the diameter of the soccer ball $2r$. That is, $2b \geq 2r$, finishing can be obtained:

$$\sin\beta \geq \frac{r}{R} \tag{38}$$

IV. Soccer shot arc and speed simulation and analysis

According to the official data of FIFA we draw the dimensions and coordinate system of the shooting area (large penalty area) considered in this paper, as shown in Figure 1.

The length of the goal is 7.32m, the height is 2.44m; the length of the small penalty area is 18.32m, the width is 5.5m; the length of the large penalty area is 40.32m, the width is 16.5m. Taking into account the actual situation and the simplification of the problem, it may be assumed that the angular velocity of the rotation of the soccer ball is vertically upward, i.e., along the positive direction of the z-axis; ignoring the change of angular velocity of the ball rotation in the process of the flight; due to the left-right symmetry of the pitch, the player can shoot with equal ability with his left and right feet. So that the athlete left and right foot can be equal to the ability to shoot, and assuming that the left and right foot or the inside of the same foot, so in the subsequent processing of the problem only consider the athlete shot at the location of the right half of the penalty area.

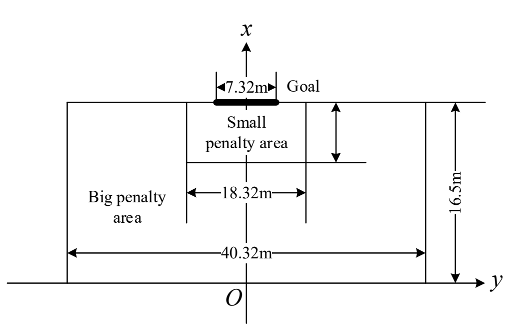

Figure 1: Schematic diagram of the shooting area (penalty area)

IV. A. Simulation and Analysis of Goal Velocity

In order to know the speed of a player's shot at various points in the penalty area when using the curling strategy, we mainly used the Monte Carlo algorithm. First, the large penalty area is meshed, assuming that the coordinates of the known shooting point are (x,y,0) and the initial velocity of the football is ($v_0 \sin\theta\cos\varphi$, $v_0 \sin\theta\sin\varphi$, $v_0 \cos\theta$), and then the subsequent movement trajectory of the football can be simulated. Here using the event function to determine whether the effective goal: when the y coordinate of the soccer ball is greater than or equal to 16.5m, the termination of the soccer ball trajectory solution operation, and then determine the termination of the moment of the soccer ball's x, z coordinate, if the soccer ball's x, z coordinates are located in the inter-goal area (-3.66m <x<3.66m, 0 <z<2.44m), it can be judged as an effective goal. And for those who have not yet reached y = 16.5m on the ground that z = 0 is not considered, that is, do not take into account the case of rebound, which is also in line with the actual game.

The generation of a set of random numbers is utilized to obtain the direction and magnitude of the initial velocity of a uniformly distributed soccer ball, and the direction interval is selected as $(0,\frac{\pi}{2})$, $\varphi\in(0,\pi)$, which means that the case where the initial velocity departs from the goal is not taken into account. The size of the initial velocity given to the soccer ball by the athlete when kicking depends on its distance from the goal, so the distance between the shooting point and the center of the goal can be considered as the maximum range corresponding to the minimum speed of the ball, so it is assumed that the athlete gives the soccer ball the minimum speed is a function of the distance r between the midpoint of the goal and the shooting position only. We find out the minimum speed required to shoot into the goal by cyclic accumulation of initial speeds, which is done by selecting some specific positions and then given a sufficiently small speed, combining with random numbers to produce 10,000 sets of angles (θ,φ) , that is, we get the initial speeds for 10,000 different exit angles. If after the judgment are not getting a valid goal then increase the initial velocity again, re-calculate and judge whether there is a valid goal. When the judgment that there is a valid goal, jump out of the loop, the current speed is defined as the minimum value of the initial velocity interval of the soccer player kicking the ball $v_{\min}$.

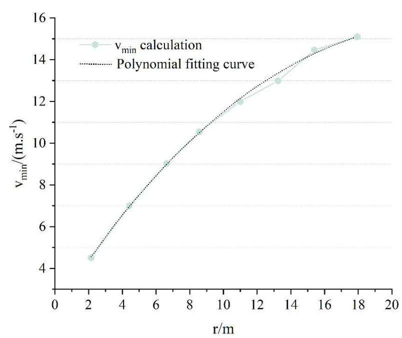

Figure 2: The relationship diagram of the minimum velocity and distance of the goal

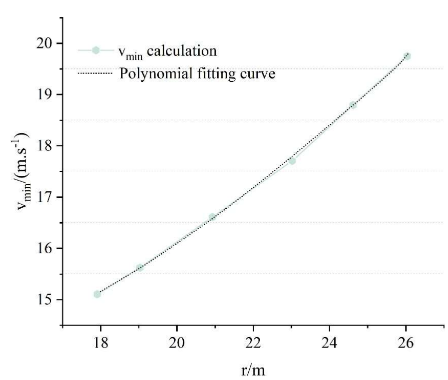

Figure 3: The relationship diagram of the minimum velocity and distance of the goal

Figures 2 and 3 show the partial initial velocity interval minimum $v_{\min}$ versus distance r found by this approach, respectively, and the scatter is fitted with the origin software, and in order to ensure the effectiveness of the fit, we use a segmented polynomial fit. In an ideal parabolic trajectory, the velocity is proportional to the square root of the maximum range, but in the case we are considering, since the ball is also subjected to a drag force proportional to the quadratic of the velocity, the actual maximum range-velocity relationship should have both effects. In Figure 2, when the velocity is small, the resistance is small and the relationship satisfied by an ideal-type parabola prevails, so the slope of the image gradually decreases; in Figure 3, when the velocity is large, the resistance is large, and a larger initial velocity is needed to reach the expected maximum range, so the slope of the image gradually increases again.

The fitting functions for the two intervals are:

$$\begin{cases} v_{\min} = 2.149 + 1.194r - 0.026r^2 \\ \quad (0 < r < 17.9m) \\ v_{\min} = 12.402 - 0.137r + 0.016r^2 \\ \quad (17.9m < r < 26.1m) \end{cases} \tag{39}$$

Among them, 26.1m is the furthest distance from the center of the goal in the penalty area. The correlation coefficients of the above two polynomial fits are 0.997 and 0.999, respectively, and the correlation coefficients tend to be close to 1, which indicates that the polynomial fits are highly accurate.

The next step is to determine the maximum value of the soccer ball shooting speed, and it is learned that for male professional athletes, the average value of the general ball speed of their kicks is 26.4±2.0m/s, and the data itself varies from person to person. In this paper, we might as well set the athlete's maximum shot velocity at 30 m/s. This gives the initial velocity interval given to the soccer ball by the athlete as $v_{\min} < v_0 < 30$ m/s, and then based on the idea of Monte Carlo Algorithm, we use MATLAB to generate N random-sized initial velocities within this set of intervals:

$$v_0 = (30 - v_{\min}) \times rand(1:N) + v_{\min} \tag{40}$$

where the n th random initial velocity v_0 combined with the n th random angle θ, φ, then you can get a total of N groups of different initial velocities, and thus filter out the range and distribution of the values and directions of the initial velocities that can be effectively shot into the goal. In order to visualize the performance, we arbitrarily select a shooting position (3.024m, 2.2m, 0m), and plot the distribution of speeds that can be effectively scored in this case, screened in 10,000 groups of random speeds, as shown in Figure 4. The area where the dot distribution is located in the figure is the range of the velocity distribution of goals scored when the shot point is at (3.024m, 2.2m, 0m).

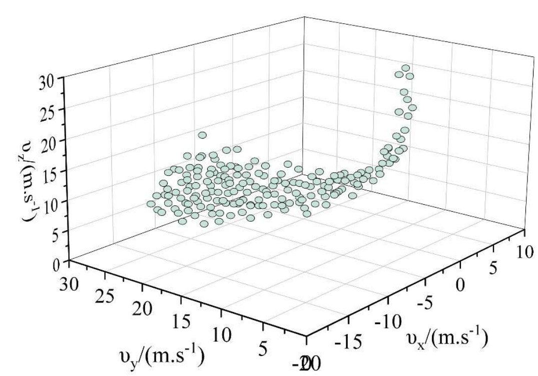

Figure 4: Goal velocity profile

For a more intuitive representation, the distribution image of v_z about v_x, v_y is made as shown in Fig. 5. The brighter the image, the larger the value of v_x and v_y at the corresponding v_z position. Therefore, it can be seen intuitively and qualitatively that when the coordinates of the shooting point are (3.024m, 2.2m, 0m), in order to be able to score a goal effectively, the ball's forward speed v_y should be larger, so that v_x, v_z can be distributed over a wide range; if you use a high pick-up ball (v_z is very large) then it is difficult to kick an effective goal because of its high restriction on the requirements of v_x, v_y.

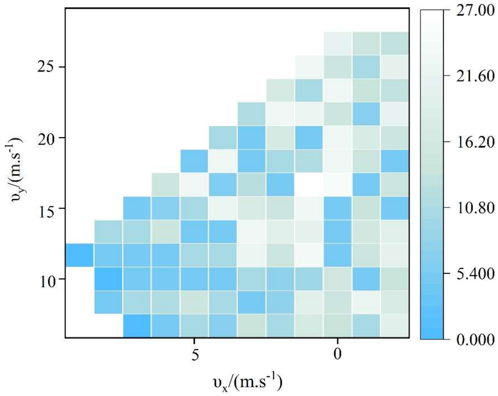

Figure 5: Goal velocity profile

In order to demonstrate the possible advantages of the curved ball when playing the game, the goal trajectories of the curved ball and the goal trajectories when the Magnus effect is not taken into account are plotted and compared as shown in Figures 6 and 7. From Figures 6 and 7, it can be seen that when using the curved ball strategy, it has a greater range of three-dimensional angles of the goal outlet, and because the soccer ball moves along the curved line, it is able to avoid the existence of obstacles on the straight line connecting the shooting point and the goal, which often achieves the effect of surprise in the real application.

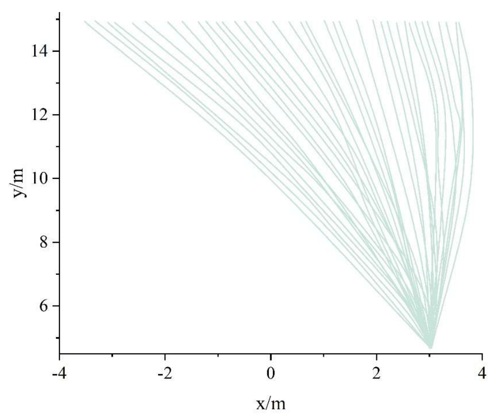

Figure 6: The arc motion trajectory simulation diagram

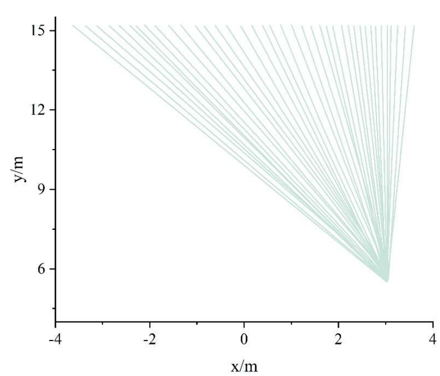

Figure 7: A model of the movement of football in the non-marginus effect

In the selection of other different positional coordinate points for simulation, it can be found in different points can be shot into the goal of the initial velocity distribution range there is a big difference, but the shape of the arc trajectory is more or less the same, can be similar analysis can be extended to other coordinate points.

IV. B. Results and discussion based on correlation analysis

IV. B. 1) Modeling the effects of correlation shot parameters

The general formulation of the correlation analysis method is as follows:

Selection of the reference series:

$$h_0 = \{h_0(k) \mid k = 1, 2, \cdots, n\} = (h_0(1), h_0(2), \cdots, h_0(n)) \tag{41}$$

where k denotes the moment.

Suppose there are m comparison series $h_i = \{h_i(k) \mid k = 1, 2, \cdots, n\} = (h_i(1), h_i(2), \cdots, h_i(n)), i = 1, 2, \cdots, m$, then it is said:

$$\zeta_i(k) = \frac{\min_s \min_t |h_0(t) - h_s(t)| + \theta \max_s \max_t |h_0(t) - h_s(t)|}{|h_0(t) - h_i(t)| + \theta \max_s \max_t |h_0(t) - h_s(t)|} \tag{42}$$

is the correlation coefficient of the comparison series h_i to the reference series h_0 at k moments. Where $\theta \in [0,1]$ is the resolution coefficient, the larger θ is, the larger the resolution is, and the smaller θ is, the smaller the resolution is, $\min_s \min_t |h_0(t) - h_s(t)|$ and $\max_s \max_t |h_0(t) - h_s(t)|$ are the two-stage minimum difference and two-stage maximum difference, respectively.

The correlation coefficient defined in Eq. (43) is an indicator describing the degree of correlation between the comparison series and the reference series at a given moment, and since there is a correlation coefficient at each moment, the information appears to be too dispersed for comparison, and is given for this reason:

$$r_i = \frac{1}{n} \sum_{k=1}^{n} \zeta_i(k) \tag{43}$$

is called the correlation of the series h_i to the reference series h_0 .

IV. B. 2) Analysis of the main factors affecting the arc and speed of the shot

Among the influencing factors generated by the performance of soccer kinematics parameters and the details of technical movements of body parts, in order to explore which are the main influencing factors, the correlation degree of 6 dimensions of 3 different distances of shooting arc and shooting speed is summed up, and the 15 factors are ranked in descending order, and the results of the influence magnitude of the arc of the shot and the speed of the shot are shown in Table 1.It influence factors and 3 different distances shooting arc, shooting speed correlation degree ranking, in order to ensure the overall explanatory power of the influence factors, the study takes the first 8 as the main influence factors in-depth discussion of the influence of the law. The eight main influences were ball initial height, ball off hand height, wrist joint velocity, elbow joint velocity, shoulder joint angular velocity, wrist joint angular velocity, knee joint velocity, knee joint angular velocity, labeled as X1, X2,... , X8.

Table 1: The results of the correlation degree of the main influence factors of different distance

Indicator label	Index name	Ranking of related degrees
F2	Ball initial height	1
F3	Ball off the foot height	2
F4	Wrist velocity	3
F6	Elbow speed	4
F9	Angular velocity of the shoulder	5
F5	Wrist angular velocity	6
F12	Knee speed	7
F13	Knee velocity	8
F7	Elbow velocity	9
F8	Shoulder velocity	10
F14	Ankle velocity	11
F15	Ankle angular velocity	12
F10	Hip joint velocity	13
F11	Angular velocity of the hip	14
F1	Action time	15

IV. C. Results and Discussion of Calculations Based on Multi-Polynomial Fitting

IV. C. 1) Multiple regression modeling

The dependent variables of the multiple linear regression model in this study were strike angle and strike speed. According to the calculation results of the influence model of the strike parameters based on the correlation analysis, the eight influencing factors were used as the independent variables of the multiple regression analysis, and the multiple regression equation was established with a total of eight dimensions, which were noted as X1, X2, ..., X8 The model of the multiple linear regression analysis established on this basis was:

$$\begin{cases} y = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m + \varepsilon \\ \varepsilon \sim N(0, \sigma^2) \end{cases} \tag{44}$$

The equations $\beta_0, \beta_1, \cdots, \beta_m$, σ^2 are unknown parameters independent of $x_1, x_2, \cdots, x_m$, where $\beta_0, \beta_1, \cdots, \beta_m$ are the regression coefficients, $m = 1, 2, \cdots, 8$ in the text.

The general formulation of the multiple regression analysis is as follows:

From (45):

$$\begin{cases} y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_m x_m + \varepsilon_i \\ \varepsilon_i \sim N(0, \sigma^2), i = 1, \cdots, n \end{cases} \tag{45}$$

To wit:

$$X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1m} \\ \cdots & \cdots & \cdots & \cdots \\ 1 & x_{n1} & \cdots & x_{nm} \end{bmatrix}, Y = \begin{bmatrix} y_1 \\ \cdots \\ y_n \end{bmatrix} \tag{46}$$

$$\varepsilon = [\varepsilon_1, \cdots, \varepsilon_n]^T, \beta = [\beta_0, \beta_1, \cdots, \beta_m]^T \tag{47}$$

Using a vector matrix, this can be expressed as:

$$\begin{cases} Y = X\beta + \varepsilon \\ \varepsilon \sim N(0, \sigma^2 E_n) \end{cases} \tag{48}$$

where E_n is the unit matrix of order n.

IV. C. 2) Regression analysis of the factors influencing the arc of the shot

Shooting arc is one of the important parameters of different distance in situ shooting, which is an important influence index affecting the hitting rate of the shot, Table 2 shows the regression analysis of the eight influencing factors of the shooting arc parameters of the three different distances of in situ shooting techniques of excellent male athletes, and the coefficients of determination, R^2, are 0.871, 0.854 and 0.849, respectively, which indicate that the explanatory power of the regression model on the dependent variable y is 87.1%, 87.4% and 84.9%, respectively. 85.4% and 84.9%, and the regression model has a good fit.

Table 2: Regression analysis results of the impact factors of the goal

Independent variable	Long shot	Aerial shot	Arc shot
D(Constant)	1.975	-0.241	44.589
X1	4.329	28.374	-44.669
X2	11.672	-11.74	33.875
X3	2.37	9.975	17.981
X4	2.085	0.194	-2.533
X5	2.661	4.527	2.655
X6	1.254	-0.418	-2.459
X7	-8.229	-8.561	1.943
X8	3.901	4.853	3.35
F	0.936	1.841	1.467
P	0.853	0.415	0.324
R^2	0.871	0.854	0.849

Therefore, the regression equation for the arc of the shot from home at different distances with the eight factors is:

$$\begin{aligned} y_{\text{Long shot}} &= 4.329x_1 + 11.672x_2 + 2.37x_3 + 2.085x_4 \\ &+ 2.661x_5 + 1.254x_6 - 8.229x_7 + 3.901x_8 + 1.975 \end{aligned} \tag{49}$$

$$\begin{aligned} y_{\text{Aerial shot}} &= 28.374x_1 - 11.74x_2 + 9.975x_3 - 0.194x_4 \\ &+ 4.527x_5 - 0.418x_6 - 8.561x_7 + 4.853x_8 - 0.241 \end{aligned} \tag{50}$$

$$\begin{aligned} y_{\text{Arc shot}} &= -44.669x_1 + 33.875x_2 + 17.981x_3 - 2.533x_4 \\ &+ 2.655x_5 - 2.459x_6 + 1.943x_7 + 3.35x_8 + 44.589 \end{aligned} \tag{51}$$

The above three sets of regression equations express the linear regression relationships of eight influencing factors of the arc of the shot from home at different distances for three different types of long-distance shots, overhead shots and curved ball shots, respectively, which express the influence of each factor on the arc of the shot and the relationship between their degree of influence. The ordering of regression coefficients is shown in Table 3.

The coefficients of the regression equation express the degree to which the regression coefficients of the factors affect the hitting rate through the arc of the shot at different distances when shooting from home. The three factors that have the greatest influence on the hit rate through the arc of the shot when shooting from a distance are the height of the ball off the foot (X2: 11.757), the knee joint speed (X7: -8.343) and the initial height of the ball (X1: 3.275).

Table 3: The goal of the shot radians and eight regression coefficients of the regression coefficients

Long shot			Aerial shot			Arc shot		
Independent variable	Regression coefficient	Sort	Independent variable	Regression coefficient	Sort	Independent variable	Regression coefficient	Sort
X2	11.757	1	X1	29.451	1	X1	-46.218	1
X7	-8.343	2	X2	-12.85	2	X2	34.573	2
X1	3.275	3	X3	9.593	3	X3	18.097	3
X8	2.894	4	X7	-8.649	4	X4	-3.214	4
X5	1.572	5	X8	4.772	5	X6	-2.785	5
X3	1.25	6	X5	4.351	6	X8	2.941	6
X4	0.864	7	X6	-0.657	7	X5	2.279	7
X6	0.073	8	X4	-0.041	8	X7	1.485	8

IV. C. 3) Regression analysis of the factors influencing shot velocity

Shot speed is another important parameter that affects the hit rate, and the results of the regression analysis of the above eight influencing factors on it are shown in Table 4. The coefficients of determination R^2 were 0.927, 0.822 and 0.985, indicating that the explanatory power of the regression model for the dependent variable y was 92.7%, 82.2% and 98.5%, respectively, and that the regression model was well fitted. The curved ball shot model P=0.034 was statistically significant.

Therefore, the regression equation of the speed of shooting from home at different distances with the 8 factors is given as:

$$\begin{aligned} y_{\text{Long shot}} &= -0.979x_1 - 0.031x_2 - 0.358x_3 + 0.072x_4 \\ &- 0.197x_5 + 0.055x_6 + 0.628x_7 - 0.166x_8 + 8.690 \end{aligned} \tag{52}$$

$$\begin{aligned} y_{\text{Aerial shot}} &= -1.887x_1 + 2.276x_2 - 0.609x_3 + 0.175x_4 \\ &+ 0.252x_5 - 0.298x_6 - 2.457x_7 + 0.447x_8 + 7.469 \end{aligned} \tag{53}$$

$$\begin{aligned} y_{\text{Arc shot}} &= -7.526x_1 + 5.768x_2 + 4.919x_3 - 1.084x_4 \\ &+ 0.873x_5 - 1.011x_6 + 0.103x_7 + 0.805x_8 + 5.674 \end{aligned} \tag{54}$$

The above 2 sets of regression equations express the linear regression relationship of the 8 influencing factors of the arc of the shot and the speed of the shot at different distances, respectively, and express the influence of each factor on the arc of the shot and the relationship of its degree of influence. The results of coefficient ordering are shown in Table 5. The coefficients of the regression equation express the degree to which the regression coefficients of the factors affect the hitting rate through the shooting speed when shooting from different distances. The three factors that have the greatest influence on the hitting rate through the shooting speed when shooting from a distance are the initial height of the ball (X1: -1.176), the knee joint speed (X7: 0.614) and the wrist joint speed (X3: -0.411).

Table 4: Regression analysis of the impact factors of the shooting

Independent variable	Long shot	Aerial shot	Arc shot
Constant	8.69	7.469	5.674
X1	-0.979	-1.887	-7.526
X2	-0.031	2.276	5.768
X3	-0.358	-0.609	4.919
X4	0.072	0.175	-1.084
X5	-0.197	0.252	0.873
X6	0.055	-0.298	-1.011
X7	0.628	-2.457	0.103
X8	-0.166	0.447	0.805
F	2.853	1.167	12.958
P	0.259	0.568	0.034*
R^2	0.927	0.822	0.985

Note: * indicates statistical significance at P<0.05.

Table 5: The shooting speed and eight regression coefficients of the regression coefficients were sorted

Long shot			Aerial shot			Arc shot		
Independent variable	Regression coefficient	Sort	Independent variable	Regression coefficient	Sort	Independent variable	Regression coefficient	Sort
X1	-1.176	1	X7	-2.515	1	X1	-7.582	1
X7	0.614	2	X2	2.231	2	X2	5.837	2
X3	-0.411	3	X1	-1.857	3	X3	4.795	3
X5	-0.257	4	X3	-0.659	4	X4	-1.238	4
X8	-0.217	5	X8	0.418	5	X6	-0.973	5
X2	-0.083	6	X6	-0.342	6	X8	0.95	6
X4	0.031	7	X5	0.23	7	X5	0.872	7
X6	0.02	8	X4	0.138	8	X7	0.18	8

V. Conclusion

The study establishes an optimized mathematical model, draws the soccer ball movement trajectory through the analysis of the arc ball, and completes the simulation model of the soccer ball trajectory. Based on the Monte Carlo algorithm, the conditions and distribution ranges satisfied by the initial speed when the arc ball is used to reach an effective goal are accurately found out, and if the shooting point is closer to the goal in the direction of the axis of the goal, the closer it is to the goal, the higher the shooting hit rate is. According to the influencing factors of soccer goal shooting, eight factors have different degrees of influence on the hitting rate when shooting at goal, among which, four factors, namely, the initial height of the ball, the height of the ball from the foot, the speed of the wrist joint and the speed of the knee joint, have the greatest degree of influence on the hitting rate when shooting at different distances through the angle of the shot and the speed of the shot.

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