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The study on factors and technology characteristics influencing soccer free kick motion trajectory

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ABSTRACT

Chinese soccer has been in low level all the time, so, in order to promote the development of football, this paper combines the rapidly-developing computer simulation technology in recent years with 3D simulation for the motion trajectory of Soccer place-kick in air to better reveal the laws of soccer motion in the air. First, analyze Soccer place-kick to obtain two ways of Soccer place-kick, and then combine the kinematics with the mechanics to study on the two kicking styles, and establish the differential equation model, afterwards, solve the differential equation models with MATLAB software, thus, the trace image of football in the three dimensional space can be worked out. This study provides theoretical basis for the soccer motion in air, aimed at making contributions to the progress of soccer teaching and training.

KEYWORDS

Differential equation model;
Three dimension emulation;
Biomechanics;
Soccer place-kick;
MATLAB.

INTRODUCTION

With the development of sports, soccer field is becoming more competitive, the two competing sides are well matched in strength, in this case, the offensive scoring opportunities are increasingly reduced, and therefore the place-kick attack tactics have become an important factor in goal. According to the statistics, about 40% of the goals come from the cooperation among place-kicks. This paper studies on place-kick balls, in which ball flight trajectory differential equations is established, the trajectory is performed simulation combined with computer technology, aimed at making contributions to the progress of soccer teaching and training. As for the soccer movement in the air, predecessors did large amounts of and put forward their views. Xu Qingyu (2005) in the mechanical analysis on the curve ball in soccer, pointed out that the curve ball has its high timeliness in the game, so, athletes should strengthen the spin kick training, and he put forward that the essentials for kicking foot is to hit the ball towards back outside, the ankle joint should reveal inward, the foot slightly upturns. If you play the ball with the outside back of foot, then pay attention to the tips of toes twisting inward, the toe fastening downwards, dados pentads[1].

Zhang Long (2007), in Four-dimensional Space-time Analysis on the Modern Football Defensive System, pointed out that, loose defense, defensive mistakes and protection failure are the main reason of losing goals, so athletes should improve psychological quality, strengthen the training to reduce the incidence of failure[2]. Xiong Zhifeng (2007), who wrote the article The study on Characteristics of Sports Biomechanics of Beckham 'curve ball, points out that Bayesian trajectory arc not only has the trajectory of parabola, but also it has strong sidespin, what' more, a comprehensive and complex motion is formed, which has the very strong concealment. As to other soccer players, it is worth learning and stimulates this aspect[3].

In this paper, on the basis of previous studies, the stress conditions of the soccer ball in the air are analyzed, and a set of differential equations model is built according to the gravity by football, air resistance and Magnus force. Combined with of the rapidly- developing computer simulation technology in recent years, the simulation solution on the three-dimensional motion trajectory is carried out, which targets at a better reveal on the football movement in the air and great contribution for the Chinese soccer career development.

THEORETICAL ANALYSIS OF SOCCER STRESS IN FLIGHT

Suppose that trajectory simulation model of a football in the air is to be set up, first, study the stress in the soccer ball in the air. Soccer in the flight process belongs to the kinematics of resistance (may also have rotation) motion of a projectile, suffer gravity G , air resistance F_d and lift force F_l . Combined with the kinematics knowledge, it can be obtained that air resistance and velocity are reverse forever. The soccer will rotate during the flight, so it causes Magnus effect, suffer the lift force. Therefore, the soccer force in the air is as shown in Figure 1.

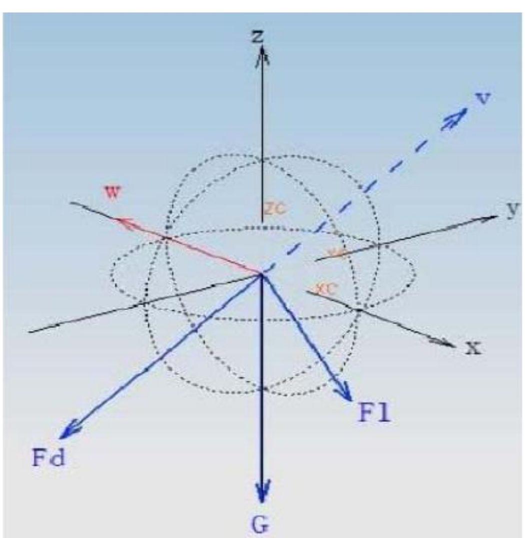

Figure 1 : Force acting on soccer in the air

Calculation and analysis of air resistance

The gravity of soccer is constantly $G = mg$ in the air, for which there is no further analysis in following parts. Besides, the air resistance can not be ignored. The air resistance is an instantaneous change in quantity, which is very complex. The basic theory on for soccer air resistance study is as follows. Suppose the football is regarded as a circular panel (as is in Figure 2).

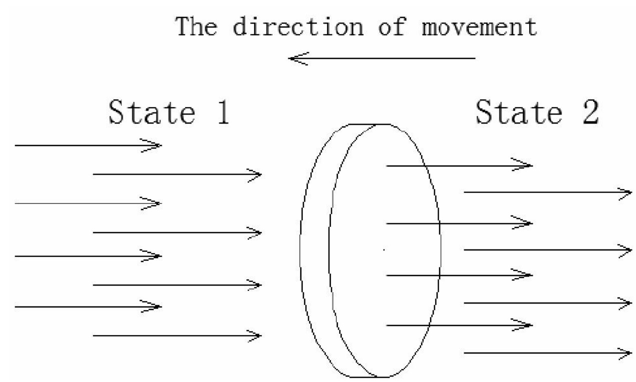

Figure 2 : The Figure of Circular plates moving in air of press difference resistance

Considering the pressure resistance for Circular plate in air, the unreached air flow is called State 1, while the reached air flow is called State 2, combined with the basic theory of the fluid mechanics, it can be seen as follows:

$$p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2 \quad (1)$$

In Formula (1), p is the pressure per unit area, if $v_1 = v$ (that is, flat movement), $v_2 = 0$, thus, the Formula can be obtained as follows:

$$p_1 - p_2 = \frac{1}{2}\rho v^2 \quad (2)$$

The back of circular plate pressure is equal to p_1 in State1, pressure difference on both sides is multiplied by the area A of circular plate, then, resistance F_d can be shown as follows:

$$F_d = (p_1 - p_2)A = \frac{1}{2}\rho A v^2 \quad (3)$$

Formula (3) is not the final formula that we want, because we need to consider the loss of velocity, the spherical friction resistance when the gas passes through the spherical surface, and more complex forms of air resistance. This paper introduced the air resistance coefficient C_d, and then the formula3 can be improved as follows:

$$F_d = \frac{1}{2} C_d \rho A v^2 \quad (4)$$

A is the maximum section of the ball, ρ is air density, v is the ball speed. By equation (4), the relationship between air resistance and all factors can be clearly seen. Air resistance is proportional to air density ρ and cross-sectional area A, the same as with the square of the velocity.

Analyses on lift force of ball by magnus effect

The Spinning ball in flight meets a lift force due to the Magnus effect, the lift force has important influence on soccer flying arc, because the rotation axis of flying in football is perpendicular to the direction of the ball motion v, then, because the speed of the above the ball and the airflow direction is opposite, the air velocity there decreases, density increases, pressure increases; and the speed below the ball and air flow are in the same direction. The air speed is faster than that above the ball, density is smaller and smaller, and pressure is the same. By the principle of the Bernoulli (Bernoulli), the gas pressure above is larger than the gas pressure below, so the gas yields a net downward pressure on the ball, and the ball movement deviates from the original trajectories so as to produce arc movement. The pressure difference is called lift force, which is due to rotation of the ball in air, and then it is related to the ball motion speed and rotational frequency, the formula (5): can be got as follows:

$$F_l = C_l \rho D^3 f v \quad (5)$$

In formula (5), C_l is lift force efficient, the paper quoted $C_l = 1.23$, which is put forward by the people like Carini J.P. D Is the diameter of the sphere, is; f is the rotation frequency of the sphere for $10 rad/s$.

DIFFERENT ANALYSIS AND MODELING ON SOCCER-KICKING TECHNIQUE MECHANICS

Soccer players most often adopt two ways to play place-kick: first, front dorsum-kick; secondly, inside and outside dorsum-kick. As for Different methods, the force of soccer is not the same, so, the two situations were analyzed and modeled as follows.

Mechanics analysis and modeling of front dorsum-kick

(1) The mechanism of front dorsum-kick

Combined with the human foot structure knowledge, it can be seen that the ball positions of contact are respectively on the first, the second or third metatarsals and phalanges when a person kicks front dorsum. As is seen from the front, the first metatarsal dorsal metatarsal is a pyramid, and the second, the third metatarsal and the phalanx is arranged in parallel to form a plane, thus the area of contacting ball is size, but the actual contacting position for the ball is not in the range of the whole foot. The accuracy outside is high, which is also the main reasons for deviation of front dorsum when one plays the ball. In order to avoid weaknesses and develop the advantages, many experienced players often adopt the way of slightly (somewhat outside

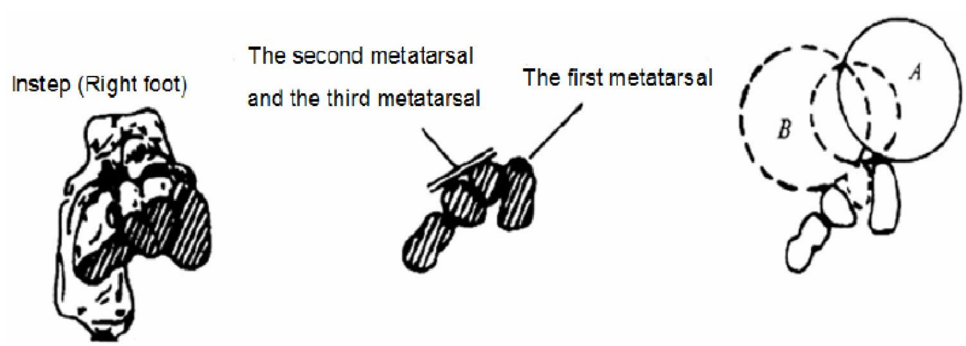

Figure 3 : The mechanism of front dorsum-kick

instep) hitting the ball with toe point so as to improve the accuracy of the mechanism, as is shown in Figure 3. So, there is almost no soccer rotation, when players adopt front dorsum-kick, meanwhile, which will be not influenced by Magnus effect.

(2) Force analysis and physical modeling for front dorsum-kick

From above, there is almost no soccer rotation, when players adopts front dorsum-kick, meanwhile, which will be not subject to Magnus effect.. Therefore only the balls are functioned by gravity and the air resistance during flight. The centre of sphere as the origin of coordinates, X shaft and Y shaft are in a horizontal plane, according to the right-hand screw rule, the shaft Z can be obtained, a 3D rectangular coordinate system is built, and the football force analysis is as shown in Figure 4.

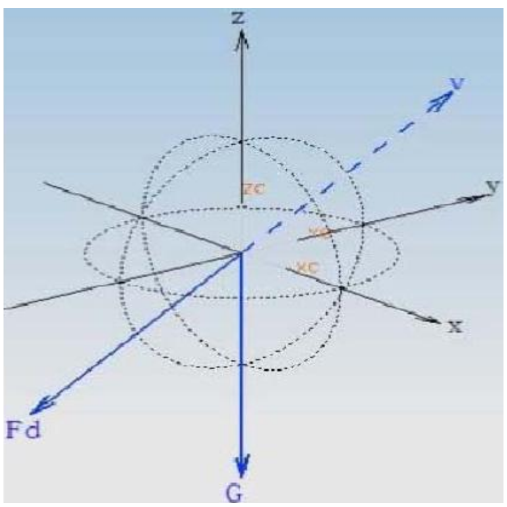

Figure 4 : The force model of front dorsum-kick

According to force analysis in Figure 4, Take the throw point as the origin point, and build 3D rectangular coordinate system $OXYZ$, both OX and OY are along the horizontal direction, OZ is in the vertical direction. Because the ball is only subject to the gravity and the role of air resistance during the flight, and the two forces are in the same plane, the plane OYZ can be only considered.

According to Newton's second law $F = ma$, the differential equation of soccer motion can be expressed as follows:

$$m\vec{a} = m\vec{g} - F_d \tag{6}$$

put formula 4 into it, the following formula can be like::

$$m\frac{d^2\vec{r}}{dt^2} = m\vec{g} - \frac{1}{2}c_d\rho A v^2 \frac{\vec{v}}{v} \tag{7}$$

Let $b = 1/2C_d \rho A$, the differential equation of soccer motion can be rewritten as follows:

$$\left.\begin{aligned} \frac{d^2y}{dt^2} &= -\frac{b}{m}\left(v_y^2 + v_z^2\right)^{\frac{1}{2}} v_y \\ \frac{d^2z}{dt^2} &= -g - \frac{b}{m}\left(v_y^2 + v_z^2\right)^{\frac{1}{2}} v_z \end{aligned}\right\} \tag{8}$$

From formula (8), the model belongs to nonlinear ordinary differential equations, which is complex. In this paper, the solution to initial value problem of ordinary differential equations in the MATLAB is adopted, and the initial conditions are determined as Y, the initial velocities for the direction of Z are respectively $5m/s$, $7m/s$ and $10m/s$, solve the equations 3 for times.

Using the variable substitution, let $y_1 = y$, $y_2 = \frac{d_y}{d_t}$, $y_3 = z$, $y_4 = \frac{d_z}{d_t}$, then, the original equations are transformed into first order differential equations as follows:

$$\left.\begin{aligned} \frac{dy_1}{dt} &= v_y \\ \frac{dy_2}{dt} &= -\frac{b}{m}\left(y_2^2 + y_4^2\right)^{\frac{1}{2}} y_2 \\ \frac{dy_3}{dt} &= v_z \\ \frac{dy_4}{dt} &= -g - \left(y_2^2 + y_4^2\right)^{\frac{1}{2}} y_4 \end{aligned}\right\} \tag{9}$$

According to the formula (9), write the document M, and put the initial value into it, football mass $m = 0.43mg$, diameter $d = 0.22m$, the density of the air $\rho = 1.20$, the air drag coefficient $C_d = 0.5$. After MATLAB operation, results can be got as shown in Figure 5:

According to the Figure 5 and MATLAB operation result, it can be known that when the initial velocity of the direction Y and Z, are respectively $5m/s$,

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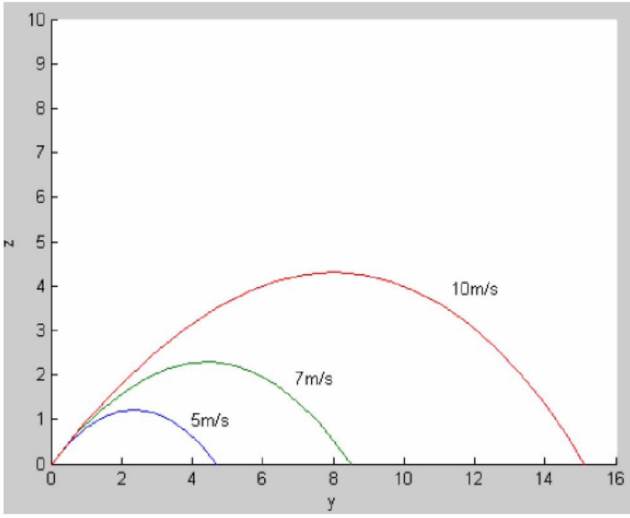

Figure 5 : The football flight trajectory of front dorsum-kick in different muzzle velocity

$7m/s$ and $10m/s$, the highest point of the trajectory are respectively $1.22m$, $2.30m$ and $2.44m$, from this, the football flight trajectory of front dorsum-kick be drawn at different initial speed instep kick football flight trajectory.

Mechanics analysis and modeling of inside and outside dorsum-kick

At the moment of kicking inside and outside, apart from force of playing ball, the ball suffers torque, so the ball will rotate in flight. Due to the rotation, the ball will be affected by the Magnus effect so as to produce a lift force. On the analysis of the stress analysis it can be obtained in Figure 6

According to press analysis, build 3D rectangular coordinate system $OXYZ$, both OX and OY are along the horizontal direction, OZ is in the vertical direction. According to Newton's second law, the differential equation of soccer motion can be expressed as follows:

$$m\frac{d^2\vec{r}}{dt^2} = m\vec{g} - \frac{1}{2}C_d\rho A v^2\frac{\vec{v}}{v} + C_L\rho D^3 f\vec{v} \quad (10)$$

During the flight of the ball, the directions of velocity and angular velocity are respectively as follows:

$$\vec{v} = v_x\vec{i} + v_y\vec{j} + v_z\vec{k} \quad (11)$$

$$\vec{w} = w_x\vec{i} + w_y\vec{j} + w_z\vec{k} \quad (12)$$

According to $\vec{h} = \vec{w}\times\vec{v}$, $\vec{h}$ can be expressed as follows:

$$\vec{h} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ w_x & w_y & w_z \\ v_x & v_y & v_z \end{vmatrix} = (w_y v_z - w_z v_y)\vec{i} + (w_z v_x - w_x v_z)\vec{j} + (w_x v_y - w_y v_x)\vec{k} \quad (13)$$

$$|\vec{h}| = \sqrt{(w_y v_z - w_z v_y)^2 + (w_z v_x - w_x v_z)^2 + (w_x v_y - w_y v_x)^2} \quad (14)$$

According to the known $c = C_l\rho D^3 f$,

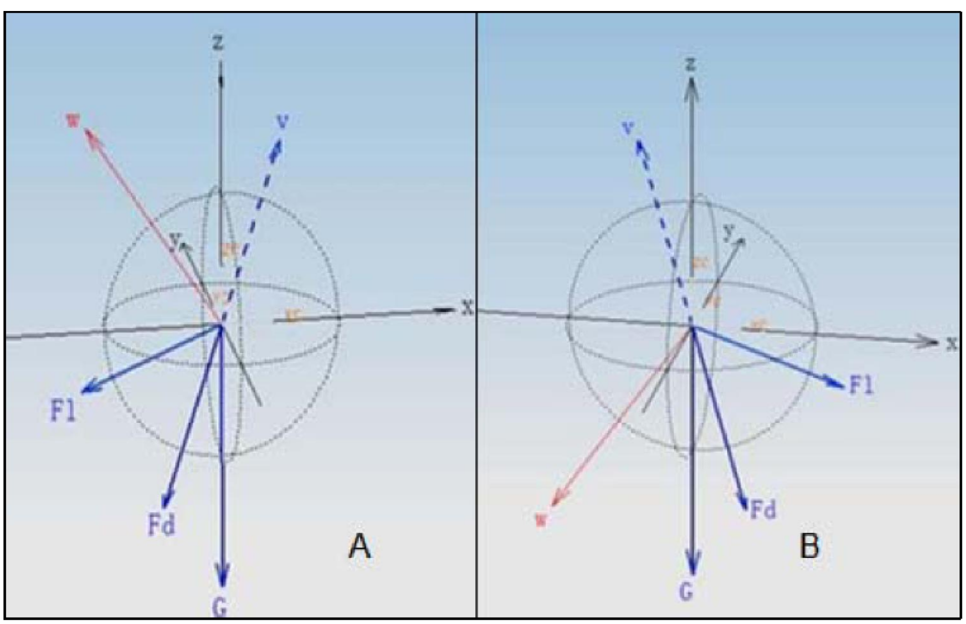

Figure 6 : inner(A), outer(B)dorsum-kick mechanics model

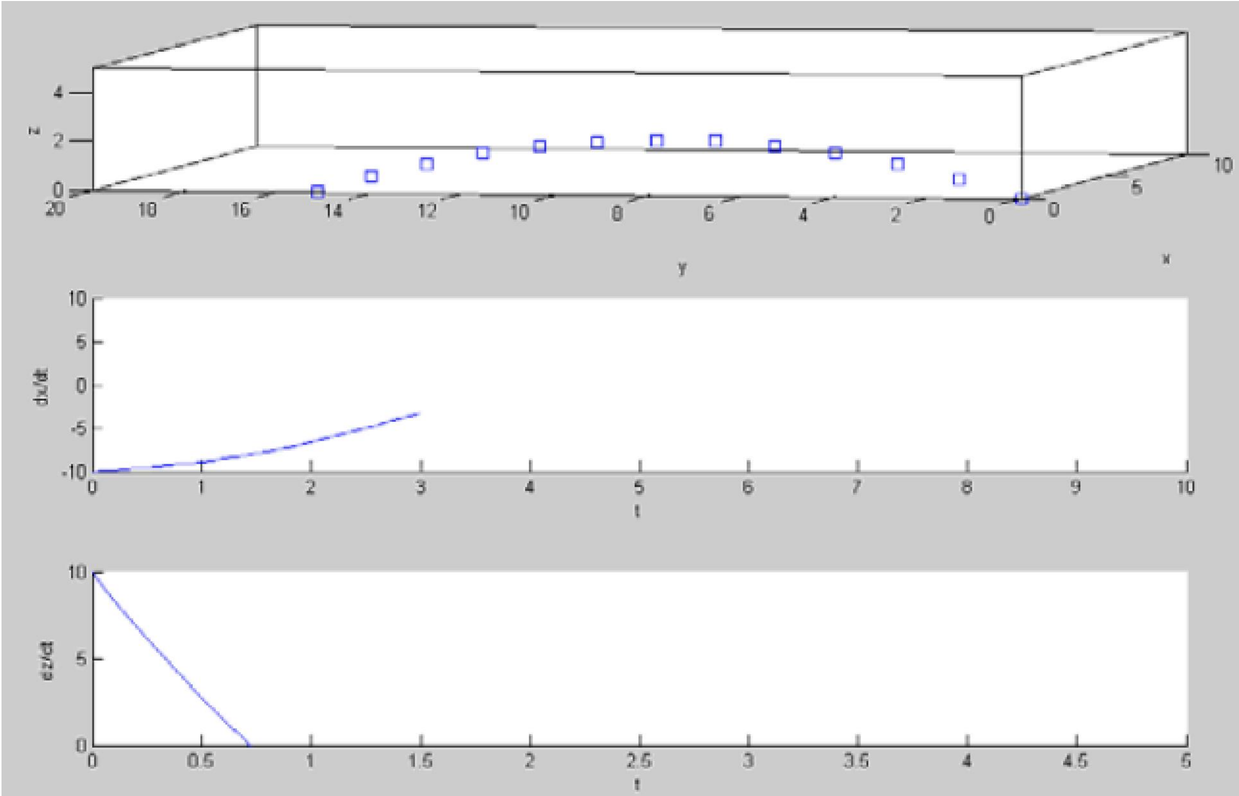

Figure 7 : The football flight trajectory of outside dorsum-kick

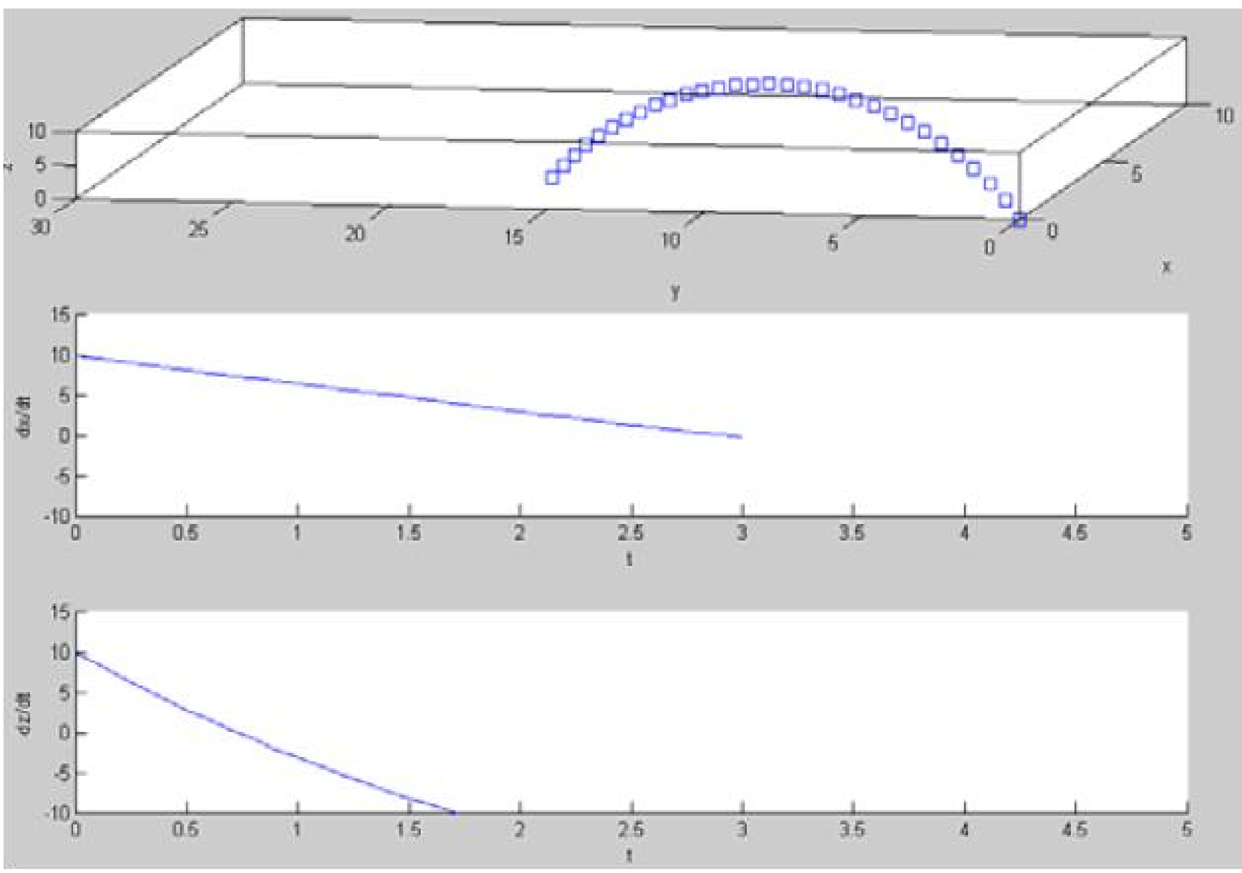

Figure 8 : The football flight trajectory of inside dorsum-kick

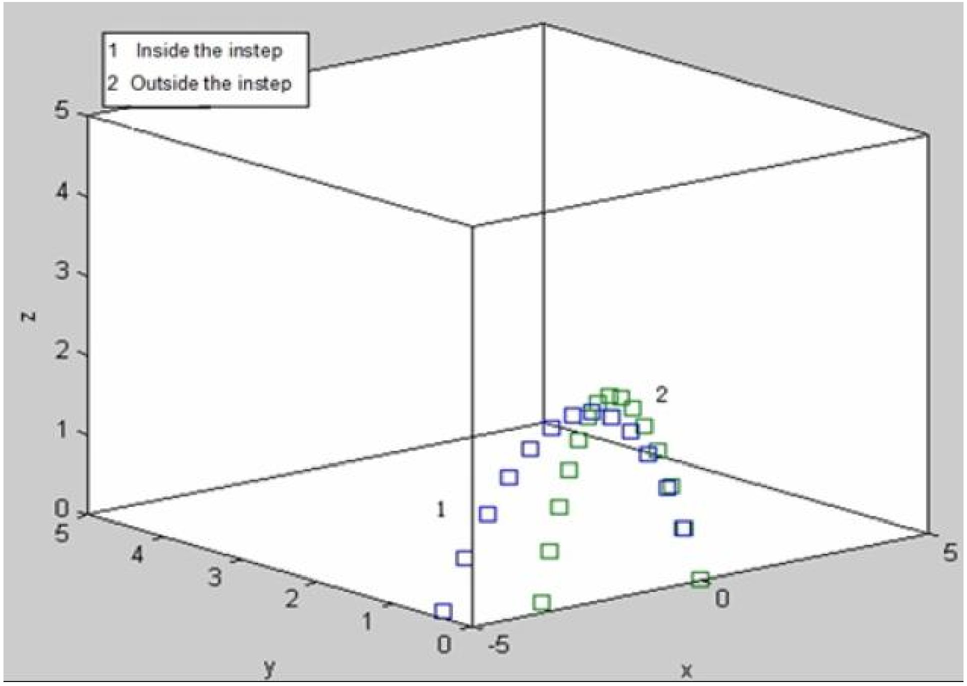

Figure 9 : The football flight trajectory of inside and outside dorsum-kick

then $\overrightarrow{F_l} = c\vec{v}$, the differential equation of soccer motion can be rewritten as follows:

$$\left.\begin{aligned} \frac{d^2x}{dt^2} &= -\frac{b}{m}\left(v_x^2+v_y^2+v_z^2\right)^{\frac{1}{2}} v_x + \frac{F_{lx}}{m} \\ \frac{d^2y}{dt^2} &= -\frac{b}{m}\left(v_x^2+v_y^2+v_z^2\right)^{\frac{1}{2}} v_y + \frac{F_{ly}}{m} \\ \frac{d^2z}{dt^2} &= -g-\frac{b}{m}\left(v_x^2+v_y^2+v_z^2\right)^{\frac{1}{2}} v_z + \frac{F_{lz}}{m} \end{aligned}\right\} \quad (15)$$

Among them:

$$\left.\begin{aligned} F_{lx} &= \frac{c\sqrt{v_x^2+v_y^2+v_z^2}}{\sqrt{\left(w_y v_z - w_z v_y\right)^2 + \left(w_z v_x - w_x v_z\right)^2 + \left(w_x v_y - w_y v_x\right)^2}} \left(w_y v_z - w_z v_y\right) \\ F_{ly} &= \frac{c\sqrt{v_x^2+v_y^2+v_z^2}}{\sqrt{\left(w_y v_z - w_z v_y\right)^2 + \left(w_z v_x - w_x v_z\right)^2 + \left(w_x v_y - w_y v_x\right)^2}} \left(w_z v_x - w_x v_z\right) \\ F_{lx} &= \frac{c\sqrt{v_x^2+v_y^2+v_z^2}}{\sqrt{\left(w_y v_z - w_z v_y\right)^2 + \left(w_z v_x - w_x v_z\right)^2 + \left(w_x v_y - w_y v_x\right)^2}} \left(w_x v_y - w_y v_x\right) \end{aligned}\right\} \quad (16)$$

The mechanical model of outside dorsum of the right foot is similar to that of inside dorsum of the right foot, but the angular velocity and speed are in different directions, which lead to the different tracks.

In this model, the initial condition, namely, velocity components of x, y and z are $10m/s$, angular velocities are $2\pi rad/s$; The soccer mass is $m = 0.43mg$;the diameter is $d = 0.22m$, the density of the air is $\rho = 1.20$, the air drag coefficient $C_d = 0.5$. Lift force coefficient is 1.23. Through the MATLAB program, The chart can be obtained, which shows the relation between the ball trajectory and velocity varying with time in the direction of x, y, z, the Figures are as follows (Figure 7 and Figure 8).

In order to compare the flight trajectory of inside and outside dorsum-kick, in the paper, the velocity components of x, y and z are set respectively as $5m/s$, and angular velocities are 2π, angular velocity, trajectory comparison is shown in Figure 9.

CONCLUSION

This paper first analyses the commonly used way of Soccer place-kick, and study force of football in air, what' s more, the commonly used way of Soccer place-kick is divided into two categories combined with the knowledge of kinematics theory and the different kicking styles. And study the two kicking styles. Based on three forces (the gravity, air resistance and Magnus force), the movement situation of the soccer under two different ways was studied and built a corresponding differential equation model; targeting the built differential equation model, its reasonable parameters value can be obtained, and the simulation flight trajectory in 3D space can also be obtained on the basis of application of the MATLAB software.

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